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THEORIES OF SYNESTHESIA IN THE LIGHT OF A CASE OF COLOR-HEARING

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The purpose of this monograph is the presentation, in detail, of the photisms of a synesthete, and the interpretation thereof in the light of various theories of synesthesia and of classifications into synesthetic types.

The nomenclature concerned with synesthesia is confusing. Various terms frequently designate the same phenomenon, and again a single word is used by various writers with diverse meanings. So far as was possible, I have attempted to adhere to a terminology generally understood. The concept sensation-form as a substitute for quality is used to permit an analysis of the qualitative elements of photisms.

The case to be considered is a pronounced case of color synesthesia with tones as primary stimulus. D. is now a girl of twenty. The observation of her synesthesiae extends over a period of ten years. She was available for testing at practically any time and replies were checked and rechecked many times. Both paternal grandparents were musical, the father also. Maternal heredity is neutral. Synesthesia was present in the grandfather, whereas the father has no synesthesia but a very pronounced number-form. A brother shows average musical talent and no synesthesia. D. showed pronounced musical talent at an early age. At eleven years she gave a public piano recital, one number of which was an original sonata. She was graduated from high school at 16.0 years, standing in the very superior group. She is gifted with a vivid imagination in all sensory fields and is of a sensitive nature, very susceptible to any sense impressions. Her synesthesia consists of a pronounced case of color-hearing.

THE ASSOCIATION THEORY

The association theory explains synesthesia as the operation of chance associations. For the sake of clearness, a distinction must be made between extrinsic and intrinsic association. Extrinsic associations account for a tone-stimulus producing an image of a certain concert hall or the smell of a certain harbor. Intrinsic associations account for the linking of low tones with dark colors, high tones with light colors; agreeable tones with sweet tastes, disagreeable tones with bitter or sour tastes. The difference is in the chance conditions and individual variation of the extrinsic and the common bases and individually non-varying conditions of the intrinsic associations. Without this distinction or a similar one, it is impossible to analyse synesthesia, as we find it in the case here studied, into its components.

Among the investigators attributing synesthesia to chance associations of earliest childhood are Nordau, Steinbrügge, Kaiser (73), Schenckel (128), Hug-Hellmuth (71). To the associationists belong also Dessoir, Flournoy, Heming, Sokolow, Volkelt.

The reality of extrinsic association may be granted without question. It is a form of the law of contiguity and forms the basis of association as generally understood. If A calls up B, A and B, according to this law, have been experienced together at some previous time. A composition may be heard in a room with many scarlet hangings. The association of the piece and scarlet may then be created. A "flat" lowers, depresses a tone, a "sharp" raises or brightens it, the association between "flats" and melancholy or dreaminess, "sharps" and brightness may thus be created. Into this class fall such associations as: parlor—honey on bread; Chopin—green leaves in the Spring; violin—light brown, color of wood; Edgar—boiled eggs; piano tones—black and white; horn—yellow or golden; Beethoven's Lenore—red-black clouds; D♭ major—a river with the smell of a harbor; a certain tone—a red handkerchief in the kitchen; fancy—cold Boston Baked Beans; S—jolly; d—gloomy; E—pink, because "pink was my favorite color in childhood and my name begins with E"; and many others reported by various investigators.

Such associations, though probably present to some extent in all synesthesiae, are not true synesthesiae. They are common to all individuals, are a form of the general law of association, and their presence cannot be offered as an explanation of synesthesia unless we accept synesthesia merely as association. Cases in which the reactions do not

show anything else than such associations are not synesthetes. On the other hand, since the associations are general, a necessary part of all normal consciousness, every true synesthete will have also some of these associations. Frequently their operation makes the analysis of the true synesthesiae more difficult. A pupil, for example, may associate C with red. But a particular C on a piano on which the practice is done may produce a poor tone. An emotional association between C and an unpleasant color may thus interfere with the true synesthesia and modify the reactions. It is probably on this account that deviations in the reactions of even the most pronounced and complete synesthesiae occur, but these do not destroy the presence of the underlying synesthetic principle which remains entirely in the sensorial field and accounts for the relative rarity of this type.

Objections to the extrinsic association theory are:

1. A pupil getting the first auditory-instrumental associations at the piano would develop not the spectral color, but a black and white key-pitch association, since this color scheme is constantly present to sense when the instrument is played. 2. The tones, in cases of real synesthesia, call up colors alone, shifting fields of color, not the colors of the keys, sky, curtains, pictures, or other definite, external objects. Nor does questioning enable the synesthete to trace the colors to external objects. Were extraneous association responsible for the synesthesia, the color would not uniformly be dissociated from the object responsible for the color, unless the color of the object had been the most vivid of its attributes, which in many instances it is not. 3. Especially in the case of octave synesthesia, each tone could scarcely have been associated so definitely with a fixed color; in D.'s case C with red, D with green, E with yellow, F with orange, G with blue, A with purple, B with brown. Such definiteness could hardly result from a chance association of a certain pitch with a certain colored object. There remains, of course, the possibility that an imaginative child, prompted by similarities of the tone and the color series, early decides to associate each tone with a color, proceeding to give each its color as whim or chance decides. Thus the C major triad, C—E—G may consist of the three primary colors of the Kindergarten, red—yellow—blue, as it actually does in D.'s case; or, early playing with colored letter-cubes may cause letter-color association. Another subject would work out a different association. A closer study, however, of the form and quality of photisms (see Quality of Photisms) disproves this theory. The photisms resemble, far too

closely, the sensations produced by nerve stimulation along the nerve, other than peripheral. 4. Such comments of D. as "vibrato makes it shinier," "harmonics are purer than normal tones," "the colors constantly shift and intertwine," "I seem to see the color inside my head" point to a direct neural correlation. 5. New stimuli (instrumental timbres not heard before) give rise to new photisms when the experimentor has controlled extraneous influences. Associations with objects could not function in these cases. 6. D. could not react synesthetically to colored objects. Frequently, on walks and in the home, when well-marked colored objects, flowers, leaves, butterflies, papers, furniture and so on, were met, D. was asked what tone they suggested. The answer was almost invariably "none." However, when colored glass was placed close to the eyes and the subject seated before a white wall, the colors at times definitely suggested tones. These facts indicate that, at least in the case of D., the extrinsic association theory cannot explain the synesthesia. 7. Since extrinsic association is constantly at work—we are all receiving visual impressions, normally, with auditory—synesthesia should be a much more frequent phenomenon, and the rather definite line between true synesthetes and others would be obliterated. This, however, is not true. Galton (26) found synesthesia in but 3 per cent of the general population; Calkins (26) found it in between 6 per cent and 15 per cent of college students. Moreover, true cases of synesthesia stand out so prominently from the non-synesthetic cases that the assumption of fundamental differences is forced upon us. 8. Lack of fusion likewise argues against the association theory. If extrinsic association functioned, knowledge that blue and red yield purple would cause purple to be imaged when red and blue (C—G) are sounded. But in D's case it was not imaged. Moreover, the visual presence of a green, when blue and yellow are sounded, fails to merge the two colors into a green, all three remaining in consciousness.

Intrinsic associations are those resulting from similarity in the sensorial material of the various senses: dark colors with low tones; high tones with sharp touches; soft tones with pale colors; agreeable tones with agreeable tastes or smells. The reality of these associations is amply shown in the later analyses of pitch, intensity, duration and emotional tone. Since they are primarily based on what I have termed sensation-form, (sensorial similarity in quality), they are common to all individuals. The fact that not all persons readily give proof of this association results from the typical difficulty of introspection, especially

in comparing sense material of one department with that of another, and individual differences in richness and facility of association. Intrinsic association is a more important element of synesthesia than extrinsic. It is present, in some form, in practically all cases, even the pronounced sensorial type. But, if it alone were responsible, we could not have the wide individual variations in the sensory data which are unmistakably revealed when the synesthesiae of various reactors are listed. These variations are strikingly shown in the tables given under The Vibration Theory.

Many investigators have assumed that all synesthesia is such an association, and, when not, that it is of the extrinsic type. Although a few instances can be so traced out, there are other features which fall beyond both intrinsic and extrinsic association fields.

These reasons do not exclude extrinsic and intrinsic associations as factors in, or phases of, synesthesia. Even in the most marked cases these elements may operate; but they do not explain the basic principle of synesthesia.

Wheeler and Cutsforth (146) advanced an explanation which, although it can scarcely be called associative, yet falls under such a general class since it does not consider synesthesia other than a normal type of mental reaction. Langfeld (82) summarizes their findings as follows: "Synesthesia is not due to an organic condition of the brain, such as a 'tangling of the fibres' but rather it is a normal and essential function for the subject, a cognitive process differing in no respect from any other process of meaning."

Against this theory we have the evidence of synesthetes that, until their attention is called to the phenomenon, they were not aware of its presence. And if it were a normal process, the complete inability of normal persons to give evidence of it could not be explained.

This interlacing of associative factors has resulted in various classifications of synesthesiae.

Flournoy divides them into four classes: induit objectivé, localisé, imaginé, pensé. If the first two are combined we have approximately the classification of Jaentsch, pointed out by Wellek: sensory, imaged, thought (*Wahrnehmung, Vorstellung, Gedanke*).

A second classification proceeds from the analytic-synthetic viewpoint:

1. Tone-color = simple-simple = analytic-simple
2. Tone-complex — color = complex-simple = synthetic-simple
3. Tone — color-complex = simple-complex = analytic-complex
4. Tone-complex — color-complex = complex-complex = synthetic-complex

Wellek presents the following classification:

1. Double-sensation	(sensation + sensation)	with peripheral stimulus
2. Sequence-image (Folge-Vorstellung)	(sensation + image)	with peripheral stimulus
3. Sequence-sensation (Folge-Wahrnehmung)	(image + sensation)	without peripheral stimulus
4. Double-image	(image + image)	without peripheral stimulus

The basic condition of synesthesia is in the sensory-sensory type. This type covers specific tone-color bonds (such as E = yellow) and taste-color bonds (such as sweet = blue, bitter = orange-brown, salt = dull-red).

The case of D. belongs primarily to the photisms of the first group of any of these classifications. Although the remaining classes are present to some degree in her synesthesia, the present analysis is concerned chiefly with the sensory aspect: the direct tone-color synesthesia.

THE DEGENERACY THEORY

The short step from the abnormality of synesthesia to a possible pathology has, of course, not escaped attention and accounts for the presence of the degeneracy theory, sometimes called the "atavistic" or evolution theory.

Benedict (17) warns against observing the phenomenon since we cannot know what consequences might result. Hilbert (68), Bleuler and Lehmann (23) point out that synesthesia may be a form of atavism since there is a level in the development of animals at which no sense differentiation takes place. Nordau, quite characteristically, looks upon it as a type of degeneration (*eine Art von Entartung*). Pierce (119) quotes Myers as follows: "Their (synesthesiae) origin may, perhaps, be ascribed to the persistence of a primitive stage in the differentiation and elaboration of sensations and in the development of their functional interrelation." Neiglicki and Benedict (17) regard synesthesia as pathologic; while Chabilier, Urbantschitch (138) and Baldwin (12) consider it physiologically normal.

It is not difficult to point out the fallacy in this theory. In the first place, it is in conflict with the general findings that synesthetes are typically intelligent, cultured and sensitive. Of hundreds of cases examined, this association of intelligence, sensitivity or imaginativeness with synesthesia is constantly pointed out by investigators.

Galton (26) writes: "Synesthetes are apt to be imaginative, introspective, shy and sensitive. They frequently have talents along musical and artistic lines. In a surprising number of cases the subject is described as very intelligent." He considers the fact established that synesthesia is not a mental abnormality in a degenerative sense. Evidence of this imaginative phase is furnished also by the frequency with which synesthesia occurs among musicians, whose auditory area would

be maximally developed. Scriabin, Weber, Wagner are a few of many examples. Chalupecký (29) points out that synesthetes are rich in imagination and are artistic.

In the second place, atavism or degeneracy is a general phenomenon sensorially, spreading over a considerable physiological area, hence it would produce an undifferentiated mass of co-sensations, whereas true synesthesia is conspicuous in its fine definition, its acute differentiation of color and pitch, taste or smell. A general lack of differentiation would be equivalent to the convulsive reflexes, such as are induced by strychnine. If senses reacted similarly, multiple response and wide diffusion would result, a condition directly opposite to that found in synesthesia. It is for this reason that the theory of Stöhr, found in Winkler (149), cannot hold. He assumes a general nerve conduction in which sensations occurring in periphery reach central neurones and thence again various peripheral organs. If this were a general plan, synesthesia would exist among all organs and for all persons. This criticism applies as well to Chalupecký's explanation: that synesthesia is the result of a hyper-sensitivity of the entire cortex, rather than a cortical hyperasthesia. Such reactions would result in a general transfer: almost any tone or tone-mass, for example, would awaken a vague conglomeration of visual stimuli since the stimulus would affect a considerable part of a cortical area.

The opposite extreme view as to the abnormality of synesthesia is expressed by H. Werner (144): "Synesthesia is in no sense merely an exceptional curious manner of perception (*Wahrnehmung*) but stands, instead, central in the problem of the development of perception itself."

Wallaschek finds in synesthesia the origin of instincts, a conception which, like the preceding, is definitely opposed to the degeneracy theory, and considers the phenomenon a normal, or better, modal reaction.

THE COMPENSATION THEORY

According to the compensation theory, synesthesia is the shift from a defective sense department into a better developed one. A defective hearing, for example, causes the subject to shift images into the visual field, if this be better developed.

Pierce (118) found the hearing in his subject defective; Downey (44) found taste defective; "taste of bitter, which showed the most defectiveness, was the one most definitely accompanied by color." Myers (107) reports a synesthetic subject hearing a minor third, a minor sixth and a major second as one tone, hence we may infer poor auditory discrimination. Hug-Hellmuth, herself a photismic synesthete, is described as very unmusical. (The synesthesiae listed in her case, however, belong to the associative class, hence do not affect sensorial acuity.)

It is not safe, however, to infer from this transfer the relationship of cause and effect. We cannot safely say that because a sense is defective, synesthesia transfers the sensations to a more highly developed sense-department in order to improve the reactions of the subject. Numerous examples can be quoted in which both sense departments are very highly developed. Conspicuous among these is the case of the Nussbaumer brothers, one of whom, especially, had a remarkably fine sense development. And, in the case of D., auditory, color and kinesthetic sensations, measured by various tests, are decidedly superior, and sensory acuity in smell and taste is at least normal; in fact, these senses, too, point to superior acuity. Edward Grasse, the blind violinist, rates his hearing and smell as his two most highly developed senses. Yet, all his synesthesiae occur between the two and are mutually reactive. Numerous investigators have called attention to the fact that synesthetes, instead of showing sensory inferiority, show a characteristic superiority, for example, the numerous cases of colored-hearing among musicians.

Furthermore, from the pronounced preponderance of photisms (seeing colors when tones are objectively present) over phonisms (hearing tones when colors are objectively present), we should have to conclude that audition is uniformly less developed than vision. This rules out the many cases of synesthesia present among musicians whose auditory sense would naturally be the most highly developed. The validity of the theory of compensation between sense-departments is opposed also by the deterioration of synesthesia with age. If synesthetic transfer were a cognitive process, a mnemonic shift or support, practice in the given field would necessarily result in a strengthening of the synesthetic bond. But this is not generally true. In the case of D. in spite of daily association with tones (many times for five or more hours per day) the synesthesia became vaguer from year to year, a fact voluntarily commented on by her during the tests made in 1932.

It follows, therefore, that we cannot accept the compensation theory as an explanation of the phenomenon of synesthesia, since too many exceptions exist of undoubted high sensorial development in the primary sense department.

THE PSYCHOANALYTIC THEORY

It was natural that the psychoanalyst should trace synesthesia to the sex experiences of childhood; thus Hug-Hellmuth (71), Pfister (115), Hitschmann (142) and later Sadger (142). The explanations, so far

as the data given make analysis possible, belong to the extrinsic association type, and, apart from the improbability of the associations, do not, in any case, fall into the sensory types of true synesthesia, since they postulate an original simultaneous experience—even though only a single experience—between primary and secondary member.

THE VIBRATION THEORY

The frequency with which color synesthesia repeats itself in octave form has resulted in the formulation of what may be called the vibration theory. According to this theory the waves of the solar spectrum are multiple frequencies of those of the tonal octave. If *24n*, *27n*, *30n*, *32n*, *36n*, *40n*, *45n* and *48n* are frequencies in a tonal scale of one octave range, then a multiple (*m*), producing *24nm*, *27nm*, *30nm*, etc., would give the frequencies of the colors corresponding synesthetically to the tones. This hypothesis is at the bottom of most of the attempts to construct a color-scale paralleling the tonal scale. The theory itself is fascinating, and much time has been expended in developing an art of color-music based upon this or similar relationships of frequencies.

In synesthesia, however, the actual photisms recorded vary to such an extent that the theory is entirely untenable apart from the fact that the ratios among the light frequencies differ too widely from the scale-tone frequencies. Taking the mid-point of the wave-length ranges as given by Listing we have: red 6850, orange 6160, yellow 5800, green 5335, blue 4735, indigo 4395 and violet 4105. Reducing these to the lowest terms: 1370, 1232, 1160, 1067, 947, 879, 821. Reversing the order for frequency (since frequency varies inversely as wave-length) we have 821, 879, 947, 1067, 1160, 1232, 1370. A diatonic tonal scale with a key-note of 821 would give 821, 924, 1026, 1095, 1232, 1368, 1540, 1642.

On the other hand, the following closely parallel series has been used to prove the frequency agreement and to establish a common tone-color scale. Assuming the frequency of brown as 760-770 and placing this equal to 1, the approximate mid-points of the solar scale would be: red-1.123, orange-1.246, yellow-1.331, green-1.493, blue-1.655, violet-1.868. A pure diatonic scale whose tonic is 1 becomes 1.125, 1.25, 1.33, 1.5, 1.67, 1.87. But if such an agreement operated in synesthesia, then all synesthetes would have the same distribution of colors and synesthesia would be a phenomenon common to all.

Neither is true. There is practically no agreement in the photismic scales of synesthetes. Table 1 is a list of the tone-color associations recorded by various investigators. (The numbers following names are bibliographical references.)

TABLE 1

Tone-color Associations

		C	D	E	F	G	A	B
Colman	(35)	blue	navy blue	yellow	brown	green	white	black
Anschütz	(10)	pale blue white	reddish brown	pure white	red brown	grey	brilliant yellow	yellow red
Preyer	(10)	brown	red	orange yellow	yellow	green red	blue	violet
Hauth	(31)	blue						
Chalupecký	(31)	yellow	bright red	pale green	grey	light brown	dark brown	black
H. Hein	(65)	rose	green	brown	violet	orange	green	yellow
D.	(—)	red	green	yellow	orange	blue	purple	brown
Myers	(107)	brown	vermilion to pink					

Another table (142) recording the synesthesiae of ten subjects follows:

C 5 as white, 3 as red
D 2 as grey, 1 as red, 2 as coffee color
E 1 as blue, 1 as coffee color, 1 as grey, 2 as green
F 3 as yellow, 2 as blue, 1 as green
G 3 as green, 3 as blue, 1 as red, 1 as yellow
A 4 as grey, 3 as blue
B 3 as yellow, 3 as blue, 1 as coffee color, 1 as clear blue

A similarly disparate distribution has been found for vowels: Colman (35). In twenty-one cases the frequency distribution was as follows:

	black	red shades	blue shades	brown	yellow	purple	white	grey	green
AH	4	7	6	0	3	0	1	0	0
EH	0	3	2	0	3	0	4	6	3
EE	8	3	0	0	5	0	2	1	2
OH	3	6	1	1	1	1	5	2	0
OO	2	0	2	5	3	0	0	4	2

The total lack of agreement in these color-scales definitely rules out the vibration theory as an explanation of synesthesia. Investigators have long been aware of this lack of agreement. Its undoubted reality constitutes a difficulty which the proponents of the vibration theory cannot overcome.

THE EMOTIONAL-TONE THEORY

An explanation of synesthesia has also been sought on the basis of common emotional tone. Pleasant tones would awaken pleasant color images, and vice-versa.

Thus Bleuler and Lehmann (23) conclude: "delicate, pleasant odors and tastes make pleasant, little saturated colors." Calkins (28) says: "Color associations with music are often accounted for by an emotional middle term. When I hear that which produces pleasurable emotion, I immediately prolong this by seeing those colors which would produce the same emotion." And later: "I am naturally fond of red, which forms the foundation of my musical association, intensified into black and etherealized into pink; mixed with blue, for the passionate purple and bothered with yellow to make the sullen and bitter discord of vermilion." Smith (130) reports a subject: "'S' is jolly, companionable, 'D' is gloomy and unfriendly. Kindly letters are yellow and red; those not fancied, are blue and purple." Mercante likewise explains synesthesia on a ground of common affective tone. Chalupecký reports a girl subject of six years reacting as follows: pleasant (good) milk: yellow; bad milk: brown; sweet milk: light blue; when too sweet: dark blue.

Such remarks show clearly that a common emotional ground can account for some phases of synesthesiae. They constitute examples of intrinsic association since the emotional tone of a stimulus is an integral part of the quality and can be traced to the sensation-form. But emotional tone cannot be accepted as an explanation of the principle of synesthesia, since ample proof of its failure to operate in many cases can be deduced.

In the case of D. it was impossible to get her to array the tones of a scale in a feeling-tone distribution. She found it impossible to say that any isolated tone (in the middle pitch region and at *mf* intensity on various instruments) was more or less pleasant than any other tone. Nor do I know of any case where a feeling-tone preference for a certain pitch exists. (The extraneous associations with key-signatures and so on do not enter here). D. was reasonably positive in arraying the colors on a basis of pleasantness. Using the colors of Prang, Chart IV, the order of most pleasant to least pleasant was: 1-green, 2-blue, 3-purple, 4-red, 5-orange or yellow. Repeated testing after intervening periods of several months yielded the same distribution. Yet repeated trials to find a similar tone-preference were useless. Even with suggestive questions D. failed to record any preference. On a purely sensorial basis, therefore, the emotional tone theory does not operate for this subject. If emotional tone did originally help to fix the synesthesia, its absence later in the field (auditory) in which D. is constantly at work, would be difficult to explain.

Similar results were obtained when tone-combinations and color-combinations were tried. D. found no great difficulty in combining other colors with a standard color in a feeling-tone series. Repetition of the test disclosed some small variations, shifts of one or two degrees in the scale, but not variation in the extremes of the series. The figures upon which Fig. 1 is based are averages of several tests. Tonal intervals were similarly listed. Arranged in the order of most pleasant to least pleasant they were: major third, minor third, major sixth, minor sixth, perfect fourth and perfect fifth, major second and minor seventh, minor second and major seventh. A series of intervals was counted on the basis of color pleasantness. Thus various major thirds were taken as most pleasant tonally and their color equivalents in pleasantness found (C—E, for example, is red-yellow with pleasantness 3). Other intervals were similarly compared. The result is given diagrammatically in Fig. 1, in which the color column is an average of the various intervals counted.

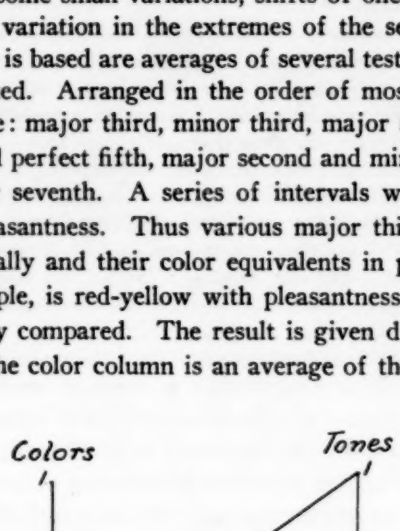

FIG. 1

The most pleasant tone combination (1) is linked by D. synesthetically with a color combination whose pleasantness is between third and fourth. The tone combination sixth in tonal pleasantness is linked with a color combination third in pleasantness.

Complete positive correlation in Fig. 1 would result in a series of horizontal lines, complete negative correlation in diagonals connecting the end-points. The results, shown in Fig. 1, prove absence of any correlation between the emotional character of color combinations and that of the tone combinations corresponding to them in this synesthesia. Moreover a single interval, such as a minor third, is in colors sometimes first in agreeableness (orange and green) and at another time last (purple and brown). Here the same tone stimulus awakens extremes of color feeling-tone in its synesthesia. Again, a perfect fifth, which D. classifies near the mid-point of the feeling-tone scale, awakens color images which are first in the scale for blue and green, second for purple and yellow, third for yellow and brown, and last for orange and red. Here the same tonal interval arouses color combinations that embrace the entire scale from most pleasant to least pleasant. A similar distribution was found for the major second. It ranked first in pleasantness for C—D (red-green), third for G—A (blue-purple) and fifth for A—B (purple-brown). So far, therefore, as specific feeling-tones are concerned no correlation exists between the sensation and its synesthetic image.

It does not follow from this, however, that no emotional correlation exists between the ear series as a whole and the eye series as a whole. For D. all the colors red, green, yellow, orange, blue, purple, brown are *per se* pleasant or rather, none is unpleasant. The same feeling-tone distribution exists for all isolated tones, at moderate pitch and moderate intensity (111). Accordingly, synesthesia, in a broad sense, may contain as one of its elements a common emotional background. If this be true, pleasant sounds would be associated with pleasant sensations in other sense departments and vice-versa; unpleasant sensations would awaken unpleasant images. If we grant that possibility, we should expect to find synesthesia present in each individual, since feeling-tone is an attribute of all normal sensations. Moreover, synesthesia would not be restricted to any two sense departments for any individual, but would spread to all sense departments containing pleasurable or non-pleasurable elements. Thus a pleasant color, let us say green, would awaken not only a tone, but perhaps the taste of sugar, the feel of velvet, the smell of a rose. This spread, though frequently found, is not characteristic of true synesthesia, which is invariably very specific and limited when compared to the innumerable associations that may function on a basis of common emotional tone. At the same time it may be, and probably is

present, in cases of true synesthesia as a secondary factor; and, on this basis, feeling-tone belongs to the class of intrinsic associations.

In the case of D. both tones and colors emotionally-toned. However, as we have seen, the emotional-tone does not determine her synesthesia. In fact, it frequently is in opposition to it, yet the synesthesia is sufficiently pronounced to maintain itself in spite of, or perhaps better, in disregard of, the emotional-tone. This not only rules out emotional-tone as a cause, but also fixes the cause as stronger than the bond of emotional-tone.

THE SENSATION-FORM THEORY

By sensation-form (111) I mean the impression upon consciousness of the simultaneous effect of transtensity, intensity and protensity; transtensity being the number, area or distribution of end-organs affected, intensity the degree to which they are affected, and protensity the length of time they are affected. The simultaneous presence of these three attributes gives the "quality" of the sensation. A tone of moderate pitch, moderate intensity and moderate duration thus has a sensation-form or quality equivalent to a touch of moderate skin area, moderate pressure and moderate duration, and a color of moderate saturation, brightness and duration. A short pin-prick becomes the equivalent of a bright spark and of a very short, high tone. The theory gains support through the association (very pronounced in the case of D.) of pitch with color, according to which minimal color effects at either end of a sensorial series increase into maximal effects near the middle of the series. In regard to pitch, most saturated colors would be found near the middle pitch region, whereas very low or very high tones would arouse little or no color images. (This must not be confused with the brightness attribute which increases to the highest pitches.) This relationship is a marked characteristic of synesthesia.

A subject of Wells (143) describes the lowest piano tones: "like toast soaked in hot water; the middle regions sweet, like licorice, banana; the high tones *thin*, insipid taste." Myers (107) reports: "256 vib. gives *clear* blue; 400 *clear* purple; 700 no definite color, perhaps *light* green; 1200 might be yellow, very *translucent;* above 2050 *faint* green or yellow green; above 6000 *colorless.*" Myers (108) for another subject: "800 vib. *light* blue; 1200 whiter—a silvery grey; 600 vib. *rich* dark Prussian blue; 1200 halfway between blue and white; 256 brown; 500 rosy-brown; 1000 *very* light blue; 1200 blue shading into grey; 4000-12000 getting more and more colorless; below C, (the lowest full octave on the piano) the subject found it hard to give color at all." Smith (130) reports: "highest tones are light; medium, dark, lowest, black." Hug-Hellmuth's own synesthesia links high tones

with bright colors, low tones with dark colors. In lower octaves brown to black; in middle octaves ascending, blue (dark to bright) in the highest octave yellow. Colman (35) "notes altered in brightness by being played higher or lower." Hein (65) concludes that lightness of color is equivalent to height of pitch. He found that in passing from g-d′ to c^3-g^3 (several octaves) the frequency of red and violet remained the same; blue showed a slight decrease; black and brown, a marked decrease; green, a slight increase; yellow, a marked increase; and white, a very marked increase. Ginsberg (53) reports a subject whose synesthesia, in order of lowest tones to highest tones is: "black brown—brown—dark red—light red—blue—green—green blue—cold blue—dull grey—silver grey—dull silver." Hein (65) reports a subject whose color synesthesia with ascending pitch was: "black—brown—blue—violet—red—grey—yellow—white." Pierce (119) describing a case of gustatory audition with a tin whistle as source of sound: "a clear, sweet flavor like Christmas candy or sugar and water. The higher the note, the less pronounced the sweet." Sweetness, here, is the equivalent of color in vision; and tastelessness, such as of pure water, corresponds to the "colorlessness" of very high tones. Further evidence of the effect of pitch on synesthesia is found in distributions such as the following: soprano voice—light blue-yellow; tenor—medium blue; baritone—dark blue; bass—brown to black. Mudge (106) writes: "high tones are equivalent to bright colors; low tones, to dark colors."

In the case of D. there can be no doubt of the association of blackness with low tones and of whiteness with high tones. Thus, on the piano, C_2—black and red; $C\sharp_1$—no color—perhaps a hint of green; D_1—green, very dirty, almost black; E—no color, very dirty orange or yellow perhaps; F_1—orange and blue, dark; A_1—dark purple; C—dirty red; D—rather dark green; F—deep orange and blue; A—a pretty purple; C^1—a beautiful red; F^1—very pretty orange; B^1—pretty brown; C^2—red, nearing pink; E^2—pretty yellow; A^2—lavender; B^2—light brown; C^2—dark pink; G^2—sky blue; B^3—real light tan; C^4—pink; F^4—no color; G^4—real light blue; C^5—the lightest pink, almost without color, water. This series has been checked repeatedly (over a period of ten years with long intervals between) without any variation in the association of lowest tones with black, low tones with dark colors, medium pitched tones with rich colors, higher tones with pale colors, and highest tones with no color. It holds also for tones produced on other instruments. As an additional check we have D.'s reactions to such combinations as the lowest C, C♯; C, D♭, D; D, E, F, on the piano. According to the sensation-form theory, the high discordancy plus the extremely low pitch should cause blackness (or absence of color) to predominate. D.'s reply to such combinations was always: "no color, much too dirty."

The frequency and definiteness of the correlation between pitch and color brightness points to it as one element of synesthesia. But we

must still make some distinction between the "dirtiness" of dissonance and that of low pitch. In dissonance the colors are distinct but dirty, in low pitch the colors themselves give way to a blackness. The equivalency of dirtiness and dissonance may, of course, result from the unpleasant emotional tone common to both.

There is, however, a distribution found occasionally that differs from that just described.

Ginsberg (53) reports a synesthesia as follows: "range of colors runs from a brown-black through a deep brown for the contra and the great octaves, then red and orange red for the small octave, red for the one-lined octave, through yellow-green, blue-green, green and green-blue for the third octave above middle C." In this case there is a fair correlation of pitch with the brightness of the spectral colors. This brightness, as established by Fraunhofer and Vierordt (153) shows an increase from red through orange to yellow and a decrease from yellow through green, blue-green, and blue to violet. The color distribution of Ginsberg's reagent contains an element of the black of low tones. This explanation, however, does not agree with that of Ginsberg. He interprets the distribution as follows: "As the tones run through a series of lighter, less massive and more tinkling, so, too, the colors run through a series from dark, heavy colors to lighter and lighter ones, until grey is reached."

According to this description, Ginsberg must react to the green and blues as brighter than the yellow-green. If so, the synesthesia must contain an element other than spectral-brightness. It probably is pitch-brightness as a result of which the spectral-brightness is modified, so that a decrease in spectral-brightness (from yellow-green to green-blue) becomes an increase in brightness because the pitch frequency has been increased and this results in an increase in color brightness. That is to say the general distribution does show (in spite of Ginsberg's remark that "the list shows not a very close, if any, resemblance to the spectrum") an agreement in passing from the reds to the orange and yellow-green to the blue. The presence of pitch brightness, however, cuts across the spectral brightness and explains the steady increase in brightness with pitch-ascent.

Intensity

A second attribute of sensations is intensity. According to the sensation-form theory, synesthesiae may be partly explained through a common intensity factor. Pale colors become the psychological equivalents of weak tones, and saturated colors become the equivalents of stronger tones. It is an association through similarity of a sensation

attribute. Data on this phase are not as comprehensive as they should be for analysis.

Bleuler and Lehmann (23) conclude that bright photisms result from high-pitches, intense pains and sharply defined touches. Louder notes give more extended photisms. Hug-Hellmuth (71) reports: "As a rule weak tones are washed out (verschwommen), strong tones dazzling (grell)," and later, "*piano and forte* weaken and strengthen the colors." English (47) reports an interesting introspection of a young child: "Soft music is yellow, loud is black, moderately loud is blue. Soft music is yellow because when you mark with yellow crayon on paper you can't see it very well, but when you mark with black, you can." Here intensity contrast determines the association. Similarly in the case reported by Azoulay (12) who saw a white light every time she heard a sudden voice in the dark.

The reactions of D. to variations of intensity were as follows:

For tones on the violoncello:

	pp	*mp*	*mf*	*ff*
C	red, watery	brighter red	still brighter red	very bright red
F♯	orange	brighter orange	still brighter orange	very bright orange
B	brown	brown	brighter brown	still brighter brown

For violin:

g	blue	little deeper blue	deeper blue	richer still
c′	red	richer red	richer red	richer still

For piano:

	pp	*p*	*mf*	*f*	*ff*
c	real dirty red	slightly darker red	still a little darker	a lot of bright red and lot of black	a lot of bright red and lot of black
*d♯	yellow-green a little black	a little more color	more yellow green	still more yellow-green	still more yellow-green
g′	bright blue-light	more color	slightly darker blue	beautiful bright blue	real brilliant blue
a♯²	real light tan, no black	more color	more color	more color	more color but not brilliant
c⁴	very, very light pink	more color	more color	more color	more color but not brilliant

* D. at this point was asked: is there any black in what you see? See also Fig. 2.

A swell on the organ "increases the clearness of the color." A crescendo and diminuendo on a reed organ, for middle C (c′) yielded the following analysis: "It is as if taking a piece of pink tissue paper and adding one sheet after another of the same color; dwindles away as if water were poured over the color, fading it." (The crescendo on the instrument was abruptly broken; it was at these points that the additional "sheets of paper" were added. Later experiments with a steady increase in tonal intensity lacked this "sheet" addition. It then was "like pouring in more paint.")

Additional experimentation with low tones resulted in an increase of both color and of black with an increase of intensity. Brilliance in the colors for very high tones could not be obtained even in the loudest degrees. The absence of brilliance for very high pitches results from the minimal amount of color present at that pitch range. A further distinction between intensity and pitch effects was given by D. as follows: "Diminishing in intensity casts a veil of grey over the color. Rise in pitch makes the color lighter, but does not weaken the clearness of the color."

From these data we may infer that, at least in the case of D., an increase in tonal intensity is accompanied by an increase in all elements of the photism. As the low C on the piano increased in loudness the red increased, but so did the black. That is to say, the individual pitch-color synesthesia increased in clearness, and the black-white—low-high association likewise increased in clearness. The color of the particular tone became more "saturated" but at the same time the darkness characteristic of all low tones became more pronounced. Thus D♯: "The louder you play it, the more black and the more yellow and green it gets in it." It was impossible to get "brilliance" in low tones no matter how hard the low keys were struck.

From D.'s reaction and the reactions of the other cases cited, an association of tonal intensity and color-saturation seems certain.

The sensation-form theory also explains why vowels produce synesthesia more frequently than consonants; tones more frequently than noises, an observation made by practically all investigators. Consonants and noises are irregular forms of vibration, vowels and tones are regular forms. The regularity sets up a "standing" sensation-pattern. There is a distinct relationship between purity of color and purity of tone—here again the sensation-forms would be similar and may act as basis for the association. It explains also Tiek (23): "The flute tone is a

smooth blue, that of the violin has *sparkle* and *shininess.*" (Sparkle and shininess in the case of D. result from rapid changes in the elements of the stimulus.)

The sensation-form theory thus accounts for two general attributes of all synesthesia: common intensity degree, resulting in the linking of weak tones with veiled colors, loud tones with saturated colors and common transtensity, (if we accept the extensity theory of pitch), resulting in the linking of low tones with darkened colors, high tones with brightened colors. Moreover, since such attributes as saturation could not be obtained for very high tones, brightness for very low tones, physiological response is evidently more limited as we approach the end of a sensorial series. But the theory does not explain the sensory aspect of individual synesthesiae, such as C with red, G with blue.

Protensity

Data dealing with the duration aspect of synesthesia are relatively scant. In D.'s case the photism was clearly sensed about two-thirds of a second after the beginning of the tonal stimulus (piano). Shorter tones than those of this duration aroused no photism. For all rapid passages, therefore, D. did not have any photisms. The presence of other tones and the characteristic diminuendo quality of piano tones reduced the clearness of the photisms still further. Accordingly, D. never spoke of them during normal work at the piano.

The time-lag between the beginning of the primary stimulus and the photism is greater than the latent time of typical reflexes. This varies with the particular reflex, but rarely exceeds one-half second (154). Accordingly, the psycho-physiological mechanism involved in synesthesia is not entirely that of the reflexes. It indicates a less completely or definitely established neural pathway, looser connections, greater resistance or greater latent time or both. If we assume a loose interlacing of fibres, and at the same time one not serving a purpose in the sustenance of the organism (which is true of synesthesia), we can account for the deterioration of the phenomenon with age. This deterioration is characteristic also of D.'s synesthesia. In this absence of physiologic function is a difference between the sensory-reflex of synesthesia and the typical efferent reflexes.

The persistence of the photism, in the case of D., after the primary stimulus had stopped was somewhat shorter (about one-half second) than the initial lag. "It does not stop immediately with the tone, but

stops somewhat faster than it starts." This "after image," if it may so be called, is independent of the original length of stimulus. So long as the primary stimulus maintains itself the photism exists. But a long stimulus (twenty seconds) did not create a more vivid photism than a stimulus of one second. And the after-lag of the photism was no longer for a long auditory stimulus than for a short one. The same constancy held also for intensity: the lag was just as short (about one-half second) for a loud stimulus as for a weak stimulus. The typical differences in color "depth" described under Intensity hold, of course, but do not affect the after-lag.

If the primary stimulus was steadily maintained the usual photism resulted. If, as on the piano, the pitch was rapidly repeated D.'s description was: "It's like an electric light that suddenly glows, then dims, then suddenly glows." (The piano tone has a characteristic diminuendo, consequently a series of a rapidly repeated pitch becomes a series of repeated intensities with each repetition, with diminuendi between. The photism, therefore, would reflect these intensity fluctuations.)

The protensity or duration aspect of synesthesia, therefore, offers no item that cannot be explained by the sensory-reflex theory. In fact, it supports the theory in the close agreement between the primary stimulus and the sensory character of the photism.

Quality

The simultaneous presence of the three sensation elements we have just considered: transtensity, intensity and protensity, produces the quality of the sensation. However, there remain certain modifications of quality which can best be treated without analysing them into their three components. Among these are the timbres of the various musical instruments, the phenomena of beats and of vibrato.

Myers (108) found that increasing the richness of a tone by adding overtones results in a "rise" in the color of the tone. Whipple (147) reports a subject who heard "Melba's voice as green, Nordica's as colorless." Hug-Hellmuth (71) finds that synesthesia is most frequently concerned with vowels, not consonants. (Vowels are relatively pure compared with consonants; the vibration-form for vowels is more steadily periodic than that for consonants.) This investigator also finds "Sympathetic voices blue-grey to steel-blue; unsympathetic (kreischende Stimmen) red-yellow. (The German term *kreischend* is equivalent to "rasping," hence rich in high, dissonant partials.)

In the case of D. I tested the effect of quality on her synesthesia under controlled conditions with the following results. One of the

strings on a piano was tuned so as to produce beats with the remaining two strings. The key used was E♭. Her reply was "a yellow-green changes in brightness." When she was asked: "It's like a shimmer, same as vibrato," she replied: "Oh, no! There is no gloss, merely a difference in brightness." The beats (about 6 per second) here produce an intensity effect, each beat resulting in a brighter yellow-green, with a paler color between the maximal beat-points. (This is interesting proof, if this were needed, that beats are an intensity variation.)

The vibrato, which is a slight shift of pitch, occurring normally from 5½ to 6½ times per second (155) had, in the case of D., the effect of adding "gloss" or "oiliness" to the color. Tested for voice, violin and violoncello the reaction was: "When the vibrato stops, the oiliness of the color is gone. When the vibrato begins again the oiliness or glossiness comes back." The beat phenomenon, on the other hand, is not a pitch variant, but an intensity variant. When the beats are very slow (one or two a second) there is present only one color saturation at a time, paralleling the plus and minus phases of the beats. When the beat-rate reaches 5 or 6 per second, the photism carries simultaneously the two degrees of saturation, producing a "mottled" field of a fundamental chroma but two degrees of saturation. (A similar phenomenon, so far as pitch is concerned, is the vibrato, which is not reacted to as a change of pitch when the rate is about 6 per second.)

Before attempting to analyse this reaction—since vibrato is a slight pitch fluctuation—it is advisable to learn what happens to the synesthesia with slight changes in pitch. For this purpose a set of Stoelting tuning forks were used: a standard of 435 and the following: 436, 437, 438, 440, 443, 447, 452, 458 and 465. D.'s replies were as follows:

S. lavender; 436: "lavender," up to 447, with no change in color; at 453: "lavender, purple but something added; don't know what it is." 458: "purple and brown"; 465: "brown and purple." This range is approximately a half-tone, which is considerably more than the pitch change of a typical vibrato (155). Accordingly, within a vibrato (less than this) there is either no color change, or a shift from one color to another and back again. In no instance of vibrato was a mention of two colors made.

In this relation between a fixed range and color we are confronted with a problem. The pitch distance C to C♯ is equal to that from C to B. Yet C does not awaken brown, whereas C♯ does awaken green (D). Again, E (yellow) does not stimulate F (orange), nor does F (orange)

stimulate E (yellow). But F♯, which bears the same pitch relationship to F as F does to E, does awaken F (orange) and G (blue) as well. Accordingly, the singly-named tones (C, D, etc.) seem to be synesthetized with single colors (red, green, etc.) whereas the modified names, C♯, E♭, etc., awaken both adjoining colors. Since there is no physiological basis for choosing C at 256 v. d. it is scarcely possible that these frequencies should have their simple physiological associates and the others, double associates. If we use the piano, the instrument with which D. has grown up, each white key awakens a single color; the black keys, with two exceptions, awaken two colors each. (The two exceptions arouse a color-blend: D♯, a yellow-green; A♭, a blue-violet.) This points strongly toward an extraneous association basis. The two exceptions, however, cannot be ignored. A♭ should produce two colors, but it does not; it produces a single color: a blue-violet; D♯ should produce green and yellow, but it produces a yellow-green.

Instrumental Timbre

Effects of instrumental timbre on the specific nature of the synesthesiae have been pointed out by most investigators. Some of these must be omitted here because the authors do not give the precise pitch-range of the tones used. Consequently, it is not possible to determine whether the color differences result from timbre or from chance pitch differences. Calkins (28) says: "The tone of a violin (blue) is very pleasurable, and blue is my color for my happiest moments." Hence, she develops the violin—blue association on the basis of common emotional-tone.

A second form of timbre synesthesia results from the operation of extrinsic association. Pianoforte tones are black and white, because the keys producing the tones are black and white. Violin tones are "wood-brown," the tones of brass instruments yellow or golden. The association here is obvious and needs no further consideration. It is a case of extraneous associations and explains many apparently synesthetic reactions.

Hug-Hellmuth (71) reports the following reaction: Violin: like the piano but with a blue background (Unterton). Horn: a blue-green background. Organ: black, violet, dark-blue. Harmonium: like the organ, but with a pronounced brown background. Starr (133) reports: Violin: red; clarinet: reddish yellow; piano: low notes black; high notes clear; guitar: blue-purple; banjo: almost like violin, but darker.

D.'s reactions to the various instrumental timbres all showed the characteristic and definite pitch-color synesthesia and, in addition, characteristics peculiar to certain instruments. The tuning-fork tones are described: "When faint they are like rainbow colors, when louder they become clearer, like the prism colors we have in our Christmas garden." Tones of the piano (middle pitch range) are: "clear and pretty, not quite so pure as the prism colors." Tones of a reed organ: "All these colors are muddy, none of them is clear; as they get higher they get lighter and a little clearer than the low ones." Tones of stopped organ-pipes (the tone from such a source is relatively pure, free from overtones, hence similar to tuning fork tone): "None of these colors is really pretty." (All these pipes were near enough for the subject to hear the hiss of air against the lip of the pipe; this noise element robs the tone, hence the synesthetic color, of its purity or clearness.) A series of organ pipes, all tuned to middle C (256 d. v.) yielded the following:

major flute: a hideous red—light grey all over.
gross flute: a hideous red—tiny bit clearer. (There was less hiss.)
melodia: red, with grey over.
gedeckt: red, with grey over. Tone seems watery.
violin diapason: dirty red.
gamba: dirty red, no gloss, dry.
viola: dirty red, dry.
dulciana: oh! that's a pretty red! clearest and prettiest you have had; some gloss.
clarinet: the red is the same (as dulciana) but streaky.
vox humana: red, a little glossy.
oboe: very ugly red.
orchestral oboe: a streaky red.
cor anglaise: a very dirty red, dry, not at all glossy.
trumpet: plain, dirty red.
French horn: rather pretty red.

The tones of an oboe produced colors all of which were "dull, lacking in clearness." When various pitches were tried on an organ the characteristic pitch—color scale appeared but during the testing D. remarked several times: "All the organ tones seem to have a purplish haze about them." Thus, low F♯: orange and dirty violet; A below middle C: pure violet (here the "background" color reënforced the original violet).

When E was given through four octaves, from low to high: "All yellows shading from dark to light and covered with a purple haze."

There is, in the case D., a close agreement between purity of tone and purity of color. A tone free from noise elements produces a color of spectral purity. When a pure tone (stopped organ pipe) is accompanied by the hiss (noise of tone-production) the purity of color is destroyed and the typical dirtiness of color results. But purity here does not mean absence of overtones, but absence of irregular vibrations. The piano tone, for example, is fairly rich in overtones but the colors seen by D. are, next to the tuning-forks, the purest. The stopped organ pipe tone is relatively free of overtones, yet the colors seen are "muddy." Accordingly, pitch clearness and color purity are correlated. Elements, such as the beating of a reed and the hissing of a column of air (all noise elements) impoverish the color.

The purplish haze and the "grey" spoken of in connection with the organ tones are probably the beginning of the colorless region resulting from noise-elements. The "haze" was vague; nor could the subject definitely say that it was always present. "It seems to be a purplish haze." The fact that with all light shut off from the retina the sensation we get is not black but rather grey, or in some cases, purple (the retinal purple) leads me to believe that the various "ground-tones" (Untertöne) may be modifications of the retinal-light phenomenon, and as such, are outside the problem of primary synesthesia.

If periodicity of vibration is the determinant of the purity of the synesthetic color, we have an explanation of the greater frequency with which vowels awaken synesthesiae as compared with consonants. For vowels are more "tonal," (frequency periodicity) than consonants. A pure tone sets up in the inner ear a fixed stable response; a pure color sets up in the retina a similar uniform response: spectral green, for example, is a one-ness, not divisible into hues or brightnesses of varying degree for any single unchangeable presentation.

On the same basis the introduction of noise-elements will destroy the purity of the synesthetic color, because noises are non-periodic vibrations, and non-periodicity in color-vision means that the vibration periodicity of the spectral colors is mixed with the non-periodicity (colorlessness) of the noise-elements, resulting in an admixture of grey.

This phase of synesthesia, therefore, is based upon maintenance of the sound pattern or of its equivalent sensation-form. When spectral blue, for example, strikes the retina, waves of a single, constant length

are acting. A "dirty" blue means the admixture of rays of other lengths so that the retina is being simultaneously stimulated by more than one wave-length. In fact if we assume grey to consist of a type of wave causing continuous variation in retinal response (as distinguished from the response to spectral colors) we should have the visual equivalent of the noise-element in audition. In fact, since white is a composition of the seven spectral colors, might not the greys be the reaction to a superposition of various combinations of these. And even black, which, with colored glass, can be produced by superimposing green and red in normal light intensity.

Chalupecký (29) reports that when the complementary color was physically presented while the subjective color was present, black resulted. This, however, does not hold for the reactions of D.

Similarity of sensation-form thus explains why pure tones produce pure colors, impure tones (noise-elements plus tonal elements) produce "dirty" colors. It explains, in the case of D., why a tuning fork C produces a "pure" red; it does not explain, of course, why the color is red instead of blue, or green, or any other color. It can also account for more complex reactions such as those described by Schubart in his: *Die Charakteristik der Tonarten.* "Innocence and simplicity are expressed by uncolored tones. Soft, melancholy feelings with flats, wild and passionate, with sharped tones."

It offers a plausible explanation of certain word-forms which connote fundamental qualities in various sensory fields. The Chinese have a single word for red, warm, bitter; another for black, cold, salty; another for yellow, wet, sweet; and one for white, dry, sharp. The Malays call grey: sweet black; true black they call bitter black.

THE SENSORY-REFLEX THEORY

The theories thus far enumerated all fall short of explaining the basic or sensorial nature of synesthesia. The theory that shows the greatest promise and that has found the greatest number of supporters is known by various names: physiological theory, *Verrirrungs-theorie,* irradiation theory, neural theory, to which I shall add, as somewhat more accurately descriptive of the neural processes involved, the name of sensory-reflex. This term defines itself; it differs from the usual concept of reflex in the omission of a motor member, and the substitution therefor of a secondary sensory member. The pitch C, for example, does not cause a reflex movement, but causes a sensation of a color: red, green,

etc., the inevitableness, simplicity and singleness of which have all the characteristics of a reflex. In other words, in such synesthesia the secondary sensation need never have been objectively present *with* the primary sensation. (This is a necessary condition for sensory associative types.)

Among the investigators advancing the sensory-reflex theory, or some form of "crossing of fibres" are: Donath (43), Downey (44) Steinbrügge (18) writes: "Either a stimulus leads from one neural path over into another, or it oversteps the specific cortical area." Thorp (136) thinks that fibres of the auditory nerve reach out, in intercerebral space, among fibres of the optic nerve. Chalupecký (29) points out the fact that certain cortical areas are not widely separated and are connected with nerve fibres. Occasionally, therefore, it is possible thus to cause mutual stimulation. This view coincides with the central irradiation theory of Nuel. Quincke (123) sees in the secondary perceptions an expression of the exceptionally manifold linking (Verknüpfung) of the cerebral ganglionic cells. Hilbert (68) admits the possibility of a connection (Überspringen) between the cortical areas themselves. A similar view is held by Urbantschitsch (138). Pierce (118, 119) also leans toward a physiological explanation.

Considerable support of a sensory-reflex explanation is furnished by certain facts of physiology. The reality of the sensory-motor arc is established. But it is known also that a sensory stimulus, resulting in its cortical activity, may, in its passage to the cortex, stimulate motor neurones without the sensation producing consciousness thereof. And, conversely, a single motor impulse may distribute itself over various sensory fibres or areas. The fact that reflex acts affect glands as well as muscles is evidence that the reflex arc is not restricted to a sensory-motor path though it does remain a stimulus-effector path. A modified example of a sensory-sensory path is furnished by the axon-reflex, which is, probably, a peripheral reflex taking place wholly through the sensory nerve fibres or through such fibres in connection with the small peripheral sympathetic ganglia. In such cases the stimulation of the sensory fibres sends an impulse back to the periphery in the reverse of the normal direction. This is known as the antidromic effect. Again, there are fibres in the optical tract that pass along the posterior border of the chiasma, which seem to belong to the auditory path, rather than the visual. Moreover, the nature of the nerve impulse, the difference in afferent and efferent fibres, artificial trunk-stimulation, all lend support to such a theory (154). With such facts already established, connections between specific sensory fibres of one cortical area and those of

another proximate area—but not mass connection—is an assumption that deserves serious consideration.

The following objections have been advanced against the sensory-reflex theory:

1. Persons not originally synesthetic can associate perceptions of various sensations and thus develop synesthesia, which would not be possible on a pre-established physiological irradiation basis.

2. The irradiation could not be sufficiently definite to account for the specific character of synesthesia. A similar difficulty exists in accounting for the prevalence of tone synesthesia and the rarity of syllable synesthesia, both of which are auditory.

3. Synesthetes are often unaware of the phenomenon until their attention is called to it. This does not point to a forcible (zwangmässige) or definitely established connection.

4. Since it is just as easy to link tones with objects or other things as it is with colors or tastes, the same process (extrinsic association) probably operates in both cases.

5. If cortical activity depends upon the number and the dendritic development of nerve fibres, the law of exercise would make it possible to develop synesthesia at will, by elaboration of the dendritic interlacing (154). This is, apparently, not true.

6. Cortical areas are intimately connected (through the association areas) in all normal individuals. Hence synesthesia, if it results from a nerve-fibre connection, should be present in all individuals instead of being restricted to a few.

The first objection is answered by the association theory already described. Such association of sensations is not truly synesthetic. The link becomes not sensory-sensory, but sensory-image or sensory-idea.

The lack of definiteness of irradiation does not add a difficulty if we assume the interlacing to occur inter-cerebrally where the nerves of common parlance are subdivided into their fibres so that a modified connection between separate fibres becomes possible.

The very fact of the secondary sensation occurring always with the primary (a necessary condition if synesthesia is basically physiologic) makes recognition of the former difficult until the attention is directed toward it.

The fourth objection holds either way. It may be possible that the same law functions for both, but it is also possible that it does not.

The connection of fibres must be considered abnormal, since the phenomenon of synesthesia (as I have restricted it) is itself abnormal in that it is present in but few persons. Furthermore, it must be accepted as established through physiological condition and not through exercise on repeated stimulation since these cannot develop it. The same observation holds for the last objection.

In support of the sensory-reflex theory we have:

1. The constancy of the relation between primary and secondary sensation. Since the secondary sensation serves no useful purpose for the organism it may fade out as the subject grows older. This is in agreement with the observed facts.

2. The involuntary character of synesthesia points to a reflex basis.

3. The inhibited reflexes are examples of the influence of one sensation upon another. Hence a sensory-sensory arc is not a new physiological assumption.

4. The frequency with which synesthesia is accompanied by high intelligence and rich imagination, both of which demand intricate cortical development, points to similar neural bases.

5. The frequency of hereditary synesthesia. The synesthesia itself is not an inheritable quantity, but the neural structure may be. (Four and five, it is true, hold also for an associative theory.)

6. The nature of the photisms differs from normal peripheral and associative stimulation. (In the case of D. this difference is certain.) It leaves, therefore, only stimulation along the neural path, or intercerebral stimulation.

7. The association between the frequency of synesthesia and the most highly developed sense areas; in man, for example, the frequency of colored-hearing. This is pointed out by many investigators (Hug-Helmuth, Hein, Lotze and others).

8. The effect of drugs, such as alcohol, haschisch, and mescal, all of which promote synesthesia usually to a very marked degree. Since their action on physiological tissue is to break down synaptic resistance, a connection between synesthesia and absence of such resistance is probable. Hypnotism (158) has a similar effect upon the richness and vividness of synesthesia.

THE PHOTISM OF D.

Fusion

In cases of auditory-visual synesthesia the phenomenon of color-fusion is useful in showing whether the photisms are cortical or peripheral in origin.

Wheeler and Cutsforth, in concluding that synesthesia is a cognitive process, a phenomenon of meaning, make it cortical. Cutsforth (146) adds: "Synesthesia is not an extraneous form of association; it is essential to the cognitive activities of the subject." Downey (44) describing a case of colored gustation reports: "The color-taste is not affected by the visual appearance of the color." Hug-Hellmuth (71) writes: "They (photisms) occur simultaneously in both sense departments. There is no after-image, nor can they be recalled." Ginsberg (53) finds: "There is no fusion of colors when tones are combined as in vision."

These findings point to a non-peripheral origin of synesthesia. That is to say the phenomenon is not merely one in which the primary sensation stimulates the nerve of the secondary sensation, with a reversed current-direction.

In order to avoid needless duplication later I give in Table 2 the complete synesthesiae of D. for tones of the piano. The piano was chosen because, next to those with the tuning forks, the photisms for piano tones were most marked. Consequently, they show details which would not be revealed by other instruments with weaker photisms. The piano series was given at intervals of six to eight months, for a period of about ten years (10-20 years for the subject), in various irregular sections so as to eliminate suggestions of order. In no case was any major variation found. The photisms and answers throughout the ten years reproduced themselves each time with remarkable sameness.

This distribution throws interesting light on the phenomenon of color fusion in synesthesia. C is red; D is green; C♯, between the two, produces both red and green in the photism. D is green, E is yellow; D♯, between the two, produces, not a green and a yellow but a yellow-green, one color instead of two. F is orange, G is blue; F♯, between the two, produces both an orange and a blue, two colors. G is blue, A is violet (purple); G♯, between the two, produces one color: a blue-violet. A is purple, B is brown; A♯, between the two, produces two colors: a blue and a brown. From this it seems that whenever two colors lie adjacent in the spectrum, they fuse in their photism; whenever they do not lie adjacent, they do not fuse. The spectrum gives R-O-Y-G-B-(I)-V. Red and green are not contiguous, but, in the case of D., they are

TABLE 2

Synesthesiae of D. for Piano Tones

*C—dirty red; black and red
C♯—no real color; hint of green
D—green; very dirty; almost black
D♯—green; so dirty
E—no real color; dirty orange
F—no color; dirty orange
F♯—orange and blue, dark
G—dirty blue
G♯—a blue-violet
A—dark purple
A♯—dark brown
B—brown, dark
c—dirty red
c♯—green and red, rather dark
d—green, rather dark
d♯—a yellow-green
e—yellow
f—orange
f♯—orange and blue, deep
g—blue
g♯—a blue-violet
a—a purple, pretty
a♯—a purple and a brown, pretty
b—brown
c′—beautiful red
c♯′—a red and a green, pretty
d′—green
d♯′—a yellow-green
e′—yellow
f′—very pretty orange
f♯′—a blue and an orange, pretty
g′—pretty blue
g♯′—a blue-violet
a′—pretty purple
a♯′—a brown and a purple
b′—pretty brown
c2—red, nearing pink
c♯2—green and red
d2—green
d♯2—a yellow-green
e2—pretty yellow
f2—orange
f♯2—blue and orange, pretty
g2—blue
g♯2—a blue-violet
a2—lavender
a♯2—brown and purple (lavender)
b2—brown, light
c3—pink, dark
c♯3—green and pink, light
d3—green, light
d♯3—no color; pale yellow-green
e3—yellow
f3—orange
f♯3—light orange and light blue
g3—sky blue
g♯3—a blue-lavender
a3—lavender, pretty
a♯3—brown and purple, very light, more like tan and lavender
b3—real light tan
c4—pink
c♯4—pink and green, very light
d4—green, so very light
d♯4—a real light yellow-green
e4—real light orange; no color
f4—real light orange; no color
f♯4—real light blue; no color
g4—pink, so very light; blue, real light
g♯4—no color; light sky blue, very
a4—no color; real light pink
a♯4—no color; real light lavender
b4—no color
c5—no color; the lightest pink, almost without color; water

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*C—lowest C on the piano.

contiguous in the tonal scale: C and D. The photism for C♯, therefore, contains both colors. Orange and blue are not contiguous in the spectrum; in D.'s tonal scale they are: F and G. F♯, therefore, produces both colors. Yellow and green are contiguous in the spectrum, also in D.'s tonal scale: E and D. Hence D♯ fuses the two and produces a yellow-green. If we assume indigo as a shade of violet, blue and violet are contiguous in the spectrum and also in D.'s tonal scale: G-A. Hence G♯ fuses the photism into a blue-violet.

Interpreted on the basis of vibration frequency D.'s synesthesia indicates that proximity of vibration frequency tends to produce fusion. Fraunhofer's lines give as the vibration frequencies in billions per second: red—450; orange—472; yellow—526; green—589; blue—640; indigo—722; violet—790. When frequencies that are adjacent in the spectral series are also adjacent in the tonal series, intermediate pitches will be a fusion of the two colors. Thus green and yellow are adjacent in both the spectral (526 and 589) and D.'s tonal series (D and E, 526 and 592). When the spectral colors are not adjacent and the tonal colors are adjacent, in pitch, the photism awakens both colors simultaneously. Thus red and green are not adjacent in the spectrum (450 and 589); but they are adjacent in D.'s tonal scale (C and D, 450 and 506). Hence a frequency between, such as C♯, 480, could not, on the basis of frequency proximity, blend the two more widely separated visual frequencies. Colors, like tones, vary directly in similarity with their vibration frequency. A color frequency of 452 billion is a red scarcely distinguishable from a red of 450 billion. A tone of 457 vibrations is a tone scarcely distinguishable in pitch from a tone of 450 vibrations. A half-step at this frequency equals approximately 28 vibrations and the vibrato pitch variation often exceeds the range of seven vibrations at this pitch (155). It is a characteristic of sensation to stimulate a "fringe" around the foveal point. That is to say the end-organs immediately adjacent to the point or points of maximal stimulation are minimally stimulated. Consequently, a stimulation at a frequency of 480, let us say, might "spread" sensorially to those equivalent to 450 and 506, but hardly to 589; or at any rate, not to 589 as much as to 506. Thus C♯ could not awaken blue, but might arouse both red and green, the two nearest frequencies. Evidence of this fringe is furnished by D.'s reaction to the tuning forks the frequencies of which fall within a whole-tone interval.

TABLE 3

Synesthesiae of D. for Tuning Forks

435 lavender
436 lavender—same color
437 lavender—same color
438 lavender—same color
440 lavender—same color
443 lavender—same color
447 lavender—same color
452 lavender; purple but something added; don't know what it is
458 purple and brown
465 brown and purple

"All these colors are like rainbow colors; when soft they are very faint, when loud they become clearer, like the prism colors in our Christmas garden."

Thus a range of at least 17 vibrations produces the same synesthetic color. Moreover, as we should expect, there is a range (452-458) at which both colors are seen before the first is definitely replaced by the second.

Additional light is thrown on this theory by a study of D.'s reactions to various diads (two-toned combinations). For the sake of completeness typical reactions for all combinations are given. (Table 4.) The two octaves above middle C were used. The series was given in non-ordered sections, with periods of several months intervening.

TABLE 4

D.'s Reactions to Various Two-toned Combinations

c′—c♯′	red and green mixed, ugly color
c′—d′	red and green
c′—d♯′	red and yellow-green mixed
c′—e′	red and yellow
c′—f′	a red-orange
c′—f♯′	a red-orange
c′—g′	red and blue; patched up together
c′—g♯′	a red-violet
c′—a′	a red-violet
c′—a♯′	a red-brown
c′—b′	a red-brown
c′—c2	red
d′—d♯′	red and green; dirty; mixed all up
d′—e′	a dirty yellow-green; one color
d′—f′	an orange-green; somewhat blended and somewhat separated
d′—f♯′	none at first; upon repetition: a pale orange
d′—g′	a blue-green; not two colors; a real blend

d′—g♯′ a blue-green; very pretty
d′—a′ green, medium and pretty
d′—a♯′ green and brown; two colors
d′—b′ green and brown
d′—c2 dirty red and green; mixed up
d′—c♯2 a dirty red-orange
d′—d2 pure, pretty green
e′—f′ a dirty yellow-orange
e′—f♯′ light-orange and orange and blue
e′—g′ yellow and blue; not sure whether any orange is between
e′—g♯′ yellow and a blue-violet mixed
e′—a′ yellow and purple mixed
e′—a♯′ yellow and brown and purple mixed; three colors
e′—b′ yellow and a yellow-brown; both pretty colors
e′—c2 yellow and red; two separate colors with some orange between
e′—c♯2 yellow and red and green mixed
e′—d2 dirty yellow-green
e′—d♯2 yellow and a yellow-green; dirty
e′—e2 yellow medium; seems like two shades, a light and a dark
f′—f♯′ trifle yellow, orange and blue; mostly orange
f′—g′ orange and blue
f′—g♯′ orange and a blue violet; very pretty
f′—a′ orange and purple; separate
f′—a♯′ orange and brown and violet; pretty
f′—b′ orange and brown
f′—c2 orange and red
f′—c♯2 orange and green and red; pretty
f′—d2 orange and green
f′—d♯2 orange and a yellow-green; ugly
f′—e2 orange and yellow, but dirty
f′—f2 orange; bottom a bit more brilliant than top
g′—g♯′ blue and blue-violet, but dirty
g′—a′ blue and purple; dirty
g′—a♯′ blue and purple and brown; pretty
g′—b′ blue and brown; very pretty
g′—c2 blue and red. Colors in themselves are beautiful but put together not so beautiful.
g′—c♯2 blue, red, and green
g′—d2 blue and green, colors pretty, put together, less pretty
g′—d♯2 a yellow-green and blue
g′—e2 blue and yellow
g′—f2 blue and orange; but they are not pretty; dirty
g′—f♯2 blue and orange, but dirty
g′—g2 blue; two shades
a′—a♯′ purple and brown; not pretty
a′—b′ purple and brown

a′—c2	purple and red
a′—c♯2	purple, green, and red
a′—d2	purple and green, pretty
a′—d♯2	purple and a yellow-green
a′—e2	purple and yellow
a′—f2	orange and violet
a′—f♯2	purple and orange
a′—g2	blue and purple; dirty
a′—g♯2	violet and blue-violet; not pretty
a′—a2	purple, two shades
b′—c2	a red-brown; dirty
b′—c♯2	brown, green, and red
b′—d2	brown and green, both pretty
b′—d♯2	a yellow-green, both pretty
b′—e2	a yellow-brown between yellow and brown on ends
b′—f2	a brown-orange
b′—f♯2	brown; orange and a little bit of blue
b′—g2	brown and blue
b′—g♯2	brown and blue-violet
b′—a2	brown and purple
b′—a♯2	brown and purple; much more brown than purple
b′—b2	brown; light shades into dark somewhat
c♯′—d′	red and green; both dirty; more green than red
c♯′—d♯′	yellow-green and red and green; all ugly
c♯′—e′	green, red, yellow
c♯′—f′	red, green, orange
c♯′—f♯′	orange and blue and red and green
c♯′—g′	blue and green and red; pretty, clear
c♯′—g♯′	red and green and blue-violet; pretty, clear
c♯′—a′	purple and red and green
c♯′—a♯′	brown, purple, red, and green
c♯′—b′	red and green and brown; not pretty
c♯′—c2	lot of red and green, ugly
c♯′—c♯2	green and red
d♯′—e′	yellow and yellow-green; dirty, like light khaki
d♯′—f′	orange and yellow-green
d♯′—f♯′	yellow-green and some orange and blue, speckled
d♯′—g′	yellow-green and blue
d♯′—g♯′	yellow-green and a blue-violet
d♯′—a′	purple and yellow-green
d♯′—a♯′	yellow-green and a brown violet
d♯′—b′	yellow-green and brown
d♯′—c2	yellow-green and red
d♯′—c♯2	dirty yellow-green mixed with a speckled red and green
d♯′—d2	dirty yellow-green and green
d♯′—d♯2	all yellow green, two shades but one shade lighter than the other

f♯′—g′ blue and orange; dirty
f♯′—g♯′ a blue-purple and a blue and orange; three colors; dirty
f♯′—a′ purple, orange, and blue
f♯′—a♯′ brown, purple, orange, and blue
f♯′—b′ brown and orange and blue; about twice as much brown as either other color
f♯′—c2 red, orange, and a bit of blue
f♯′—c♯2 orange, blue, red, and green
f♯′—d2 green and a little orange and blue
f♯′—d♯2 orange, blue, and yellow-green; pretty
f♯′—e2 yellow and a blue-violet
f♯′—f2 ugly shade; dirty; orange and blue
f♯′—f♯2 orange and a blue
g♯—a violet and blue-violet; dirty
g♯—a♯ brown, purple, and blue-purple
g♯—b blue-purple and brown; not distinct
g♯—c′ red and blue purple
g♯—c♯′ green, red, blue-violet
g♯—d′ green and blue-purple; not distinct
g♯—d♯′ blue-purple and yellow-green; two colors
g♯—e′ blue-violet; yellow
g♯—f′ orange and blue-violet
g♯—f♯′ blue-violet and blue and orange; dirty. I can see them clearly but they are dirty.
g♯—g′ blue-violet and blue—very dirty
g♯—g♯′ blue-violet
a♯—b brown and purple, more brown
a♯—c′ brown, purple, red. Red shows more than other two; has dirty grey over it.
a♯—d′ brown, purple, green
a♯—d♯′ yellow-green; brown, purple
a♯—e′ yellow, brown, purple
a♯—f′ orange, brown, purple
a♯—f♯′ brown, purple, orange. Pretty colors, separate and blend well.
a♯—g′ blue, brown, purple
a♯—g♯′ brown, purple and blue-purple
a♯—a′ violet and blue-violet; dirty, a little brown
a♯—a♯′ brown and purple

C and E produce, in D.'s case, red and yellow, but no orange. C, E and F produce red, yellow and orange. Red and yellow still remain distinct although their fusion, orange, is simultaneously present. E—G produce "yellow and blue." D-E-G produce green, yellow and blue, the blue and yellow do not fuse into green. In fact the reaction to E-G is: "yellow and blue; I am not sure whether there is orange between" and

points to a partial (fringe) stimulation of the synesthetic series between yellow and blue, instead of any hint of green. Viewing the problem from the color spectrum side we find that adjacent color frequencies fuse, or at least tend to fuse the colors. c and f—a red-orange; e-f—a yellow-orange; e-d—a yellow-green; d-g—a blue-green.

I have thus far spoken of physical-chemical pigment fusion: red-blue = purple; yellow-blue = green, etc. The absence of agreement of these fusions with synesthetic fusion holds also if we take retinal fusion into consideration. The complementary colors, fusion of which will give retinal white or gray are: red and green-blue; orange and blue; green-yellow and violet; and yellow and indigo-blue (154). D.'s synesthesia shows no such fusion. In each case the two colors remain distinct without giving any evidence of a third resultant. That is to say, when blue and yellow are superposed on the retina, white is seen. If the tones E and G set up, either by reversibility of neural conduction, or even cortically, the same stimulation, white would result. Since this is not the case, D.'s synesthesia cannot result from any visual superposition of frequencies in the retina. The same holds for any other theory of color-fusion we accept. Ladd-Franklin (157) fuses red and green radiations into yellow, not white. Accordingly, C♯ for D. should be yellow; but it is not, it produces both red and green, and even with yellow present (C♯-E) retains its red and green. D.'s synesthesia, therefore, cannot be tone-color associations based upon the typical color fusions. If synesthesia were associative, the fact that D., in early childhood, had the typical color fusions definitely established, would normally have resulted in the fixation of these associations. Her synesthesia, however, conflicts with these associations. Consequently, the synesthetic base not only is non-associative, but sufficiently fixed to remain unmodified by the frequent exercise of the typical associations.

In the case of D., relationship between the pitch and the color series groups into three classes: when contiguity in both pitch and color series is present, the colors of the photism definitely fuse into the resultant; when contiguity in the pitch series is present with non-contiguity in the color series, color fusion is absent; when contiguity in the color series is present with non-contiguity in the pitch-series, both separate colors and a partial fusion result.

Association

In spite of the definitely physiological basis of D.'s synesthesia, the extent to which association, intrinsic or extrinsic, functions, is difficult to establish. She had her first experience with letters and colors before synesthesia was suspected. Numerous remarks concerning other sensory fields and the higher forms of reaction have shown that in her case many subtle associations are at work. Her dislike of a certain blue and yellow is the result of an association with a headache remedy sold in blue bottles with yellow labels and advertised in the same colors. "Monday is 'blue' because when I was very young I remember some beautiful blue skies that came on various Monday mornings." Liszt's D♭ Etude "Waldesrauschen" is green "because of course leaves of the woodland trees are green." The colors of the Autumn leaves are pretty because "God wants to make their death beautiful." Her earliest home training even in pre-Kindergarten age subjected her to sense stimuli of many sorts, both parents devoting daily attention to mental stimulation appropriate to her age. Her acute sensory reactions favored associations of many kinds. The impossibility of tracing all such associations to their original source makes it unsafe definitely to rule out association, as a contributing factor, in such a case of synesthesia.

On the other hand, the nature of the photisms (explained in detail later) points clearly to a physiological basis other than associational. On several occasions D. was asked, after naming the photism, the letter name of the tone. She would then ask for a repetition saying: "I did not think of the letter name; play it again." In these instances, at least, the photism had not been induced by the letter-name association. (See also Table 6 for further letter-color conflict.) Then, too, repeated trials with letter names, (D. was asked to think of a color for E, A, etc.), invariably brought forth the reply: "I cannot see any color." Even when the synesthetic color was suggested to her (such as blue for G) she would reply that she could "think the color but could not see it in any way like that accompanying the tone." Table 6, moreover, definitely rules out the letter-name as intermediate common term; for, in this, b is green, c is yellow, g is red, whereas, in her tone synesthesia the colors are, respectively, brown, red, blue. For the same reason number synesthesia is not responsible, since the numbers do not correspond with the colors for either letters or tones (see Table 5).

The presence of the typical low-high—dark-bright distribution, however, the bond between "pure" tones and "pure" colors, the interactions

of dissonance and dirtiness show clearly that D.'s synesthesia contains as an important element the intrinsic association.

Tables 2 and 4 show, unmistakably, the effect of this association. It is reflected in the pitch-brightness distribution, the intensity-paleness distribution, the black-white—low-high series, the dissonance-dirtiness series, the simple-complex timbre association. This intrinsic associative element arrays the individualistic sensorial basis of her synesthesia in the orders typical of normal reaction.

Extrinsic associations, as I have already pointed out in Fusion, do not function in the synesthesia of this subject. In the first place, the most probable extrinsic associations: white-black keyboard, pitch-letter name, emotional-tone associations, are not present, and in the second place, D. was never in doubt that, whenever such a chance association was discovered, it was such an association and not a photism. "Oh, no," she would say: "It is altogether different from seeing the color."

TABLE 5

Number Synesthesiae of D.

	1925	1926	1928	1932
1.	white	.....	.....	.....
2.	blue	blue	blue?	blue?
3.	yellow	yellow	yellow	.....
4.	red	red	red	red
5.	green	green	green	green
6.	brown	brown	brown	brown?
7.	orange	orange	.....	orange?
8.	purple	.....	blue-violet?	purple?
9.	brown	black	.....	.....
10.	yellow	.....	.....	.....
11.	yellow	.....	yellow	.....
12.	red	.....	.....	.....
13.	.....	.....	.....	.....
14.	red	red	.....	.....
15.	green	green	green	.....
16.	brown	.....	.....	.....
17.	orange	orange	.....	.....
18.	purple	.....	purple	.....
19.	brown and green	.....	.....	.....
20.	blue	blue	.....	.....
21.	blue	.....	.....	.....
22.	blue	blue	blue	.....
23.	blue and yellow	vague?	.....	.....
24.	blue and red	vague?	?	.....
25.	blue and green	vague?	?	.....
	etc.			

The question of attention as a factor in synesthesia has already been mentioned. In the case of D. throughout the long periods of non-experimentation, she never herself mentioned her photisms. In the earlier experiments, the only instructions were to "close your eyes and listen." "What happens?" No mention was made of seeing anything or of color. Hence in these instances since the colors were readily named, the photism must have focussed the attention, and not the reverse. Later on when D. naturally could guess what the experiment was for, the effect of attention on inducing the photism could no longer be safely determined. (See also Localization.)

D.'s synesthesia branches out (although at 20 these phases have become very vague and sparse) into the number and letter field. I append some tables since they definitely exclude letters or numbers as determinants of her tone-color synesthesia and at least rule out these elements of association.

TABLE 6

Letter Synesthesiae of D.

	1926	1928	1932
a.	?	.....	none
b.	green	.....	
c.	yellow	.....	
d.	green	green	
e.	yellow	yellow	
f.	orange	.....	
g.	red	.....	
h.	brown	.....	
i.	.....	.....	
j.	brown	.....	
k.	.....	.....	
l.	yellow	yellow	
m.	.....	.....	
n.	.....	green	
o.	.....	white	
p.	brown	brown	
q.	blue	.....	
r.	blue	.....	
s.	.....	.....	
t.	red	red	
u.	blue	.....	
v.	.....	grey?	
w.	.....	.....	
x.	.....	.....	
y.	.....	.....	
z.	.....	.....	

Age

D.'s photisms show the deterioration with chronologic age pointed out by investigators as a typical characteristic of all synesthesia. This deterioration manifested itself in the tests made at the age of twenty. Photisms for very weak tones (readily audible, however) were no longer present; the same condition held for very short tones. A sustained tone, gradually getting softer, would arouse a photism for a time, but this would disappear when the tone became very weak, although the tone could still be heard.

Concerning timbre, the earliest photisms to become first vague and then lost were those for instruments (oboe, certain organ pipes, poor-quality voices) originally producing "dirty" and poor colors, as contrasted with the pure and rich colors of tuning forks and the piano. A similar deterioration took place for vowels and numbers, the photisms for which, in the case of D. were never as vivid as those for tones. Pitch likewise showed a loss of sensitivity. The highest and lowest octaves no longer produced photisms definitely, although pitch discrimination, if anything, had improved.

Order deteriorated. At the age of fourteen D. remarked that, "I can hear the tones from colors almost as well as I can see the colors when tones are played." At twenty the order color-tone no longer functions. That is to say, phonisms were absent. From the total reactions, it is safe to say that the phonisms probably were never as vivid and varied as the photisms.

This general loss of sensitivity may result from a deterioration of the fibril connections with age, a natural and typical phenomenon in cases where such "irradiation" serves no useful purpose in the life of the organism.

Localization

Tests made with D. to determine localization of the photisms did not lead to conclusive results. At one time she localized them in actual space, seeing the higher tones—with her back to the piano keyboard—to the left of the visual photismic field. With a two-toned clang small c and g^2, the following localization was given:

Source in rear median plane: red in right photismic field, blue in left.
Source opposite left ear: blue on top, red at bottom.
Source in front median plane: blue to the right, red to the left.
Source opposite right ear: red to lower left, blue to upper right.

When the head was in a horizontal position (face up) D. localized the higher tone as "higher in the head" (toward top of skull). The drawings of the photisms which she made were turned through 90° and 180°, and her decision as to the preferred position was rather uncertain. "I believe they go better this way but am not sure," was a typical remark. When simple octaves were given on the piano (c′ and c), with the source in the rear median plane, she saw the lighter shades to her left, the darker to her right. This is a direct transfer from the spatial localization of the auditory stimulus itself.

The fact that this spatial distribution was absent in many of the illustrations of the photism, and, furthermore, was described as very vague after attention had been directed thereto, makes definite localization rather an associative factor or a factor of attention, and not an element of the original photism. "Whenever a photism was illustrated without comment the form shown in Figs. 2 and 3 resulted: a field of irregularly shifting colors. When suggestive questions were asked, D. "thought" she saw the higher tone to the top or to the right (Fig. 5). She usually found it impossible to see the color for the higher tone at the bottom or to the left of the photismic field. Now and then, particularly if she was close to the keyboard of the piano, with her back turned, she could transfer the tones directly: higher to left and lower to right (which actually was the auditory spatial distribution).

Data on the localization of photisms have, in general, been classified into four groups:

1. Photism referred not outside body but back of eyes or in head.
2. Photism forms background of objects in field of vision without obscuring them.
3. Photism corresponds to sight of objects producing them.
4. Photism obscures objects in visual field or blends with them.

D.'s localization falls into the first and fourth classes of the given grouping. Class four enters only so far as affecting the visual field when color fields were presented to the eye. Normal objects were never described as covered with a color or as having a color background. Her synesthesiae were, without exception, localized within the head and were differentiated even from a simultaneous optical after-image. This, too, points to a physiological and not an associational basis for the photisms.

Order

At the age of seventeen D. could not get any definite auditory synesthesiae from the objective presentation of colors. Repetition of the test at twenty gave the same results. However, when she was fifteen, a series of tests with the Prang Charts resulted in what to all appearances were synesthesiae. D. was asked to "hum the tone suggested by the color." The tone "suggested by the color" could be imaged indirectly through association. D., when looking at the Green of Chart II hummed d′; for yellow, she hummed e′. When asked: "How did you get it?" she replied: "I can't tell you. I guess I knew it was E, but didn't think of it until later." For the sake of completeness I add other reactions.

Chart II, violet—A♭′. This is too high. More like the lower octave.
Chart II, orange—hummed between e′ and f′ (almost f′). "Color is not exactly f′, but too high for e′."
Chart VII, grey-orange—hummed f′-b′.
Chart VII, blue-green—hummed d′-g′.
Chart VII, yellow-orange—"This tone is between e′ and f′, too high for e′ too low for f′."
Chart VII, red-violet—c′-a′.
Chart VII, red-orange—c′-f′.
Colors at bottom of Chart VII.
grey-yellow—e′, a′; e′ is stronger than a′.
grey-orange—c′, d′, b′. b′ is strongest; then c′, then d′; rather a pretty color. I believe I'm wrong here; it is too pretty for such a dissonance. Now it seems to be f′, g′, b′. b′ is stronger than the other two, but f′ is more than twice as loud as g′.
grey-red—c′, d′, a′, b′. I hear them all but they do not make a dissonance.
grey-green—e′, d′, more d′, about three times more.
grey-blue—g′, f′, more g′, about three times more.
grey-violet—e′, a′; more a′.

The answers reveal an accurate analysis of color blends into their components, thus pointing to a superior color-sense. On the other hand, D.'s auditory reactions are also very superior, hence her photisms cannot be explained on the basis of the compensation theory. Even the ratios given for grey-blue and grey-green, 3 to 1, are correct. With such an analysis the association with the synesthetic tones could readily follow,

though, here again, there was no definite evidence that association was functioning. D.'s remarks in this respect are not conclusive. At one time she said: "It is too pretty for such a dissonance" which shows clearly the association through common emotional tone; then again: "I hear them all, but they do not make a dissonance" which as clearly rules out fusion association. I should mention here that the order color-tone seemed uniformly less facile than the order tone-color in this subject's case. (This is mentioned as a typical condition by several investigators.) Accordingly, the error of associations cutting across the synesthesic arc, if any, is increased. The results with the Prang Charts are interesting in the light they throw upon the definiteness of hue and brightness with which the synesthesia operates. As D. grew older, the order color-tone became more and more uncertain, and as stated, at seventeen years, was too vague to warrant any conclusions. The definitely negative results obtained at the age of twenty for the order color-tone and the positive replies "absolutely no tone," show a complete elimination of this phase of the synesthesia. Unfortunately, earlier experiments for the order were not made, the presence thereof, up to fifteen, must remain conjectural. It is certain, however, that it never had the vividness of the reverse order.

This irreversibility is in direct contrast to the findings of Wheeler and Cutsforth (146) who state: "The two processes: primary and secondary, are reversible. Either one will identify the other. The second to appear identifies the first."

Effect of Visual Sense-Stimulation Upon Photism

In order to test the effect of a visual color, objectively present, upon a photismic color, tones of one color were presented while the eye looked through colored glass. These glasses were held close to the eye and the eye was directed at the centre of a large, white sheet, so that the entire field of vision consisted of a uniformly colored area with no external objects visible, even in peripheral vision. The tones were given on a piano. When G (blue) was played with a red visual field, D. replied: "The red color does not change, but blue is there. I don't see it as I do the red, but it's like subconscious." The same introspection was given for various other combinations.

A second test consisted in keeping the visual field constant and playing a scale slowly (red-green-yellow-orange-blue-violet-brown). With a blue visual field the following introspection was made: "The blue re-

mained fixed. But something seems to struggle against it. When G (blue) is played, this struggle stops and everything seems to merge. It is as if my mind were struggling against my eye." D. had no difficulty in naming the photismic colors while looking through a glass of another color. "It's hard for me to explain. I know the color is there, but I don't see it with the eye."

A third test consisted in having D. look at the colors of Prang Chart, (red, yellow, blue, orange, purple). Then certain tones were played, one at a time. As the tone corresponding to a color was heard, that color "stood out" from the others.

D.'s definite distinction between the objective nature of the field of color and the subjective nature of the photismic color, seems sufficiently pronounced to rule out any peripheral nature of synesthesia. Her inability to describe the association or to localize it elsewhere than "in her mind" points to a cortical or at least non-peripheral origin. Moreover, since the objective color can remain in consciousness while the photismic color is also there, the cortical stimulation cannot be the same in both cases. Otherwise, the two sensations would fuse into one. This seems to occur when the physical color and the photismic color are exactly the same. The physical color, however, was not that from an external object, but a field of color covering the entire visual field.

This also seems to point to stimulation along the neural-path, at any rate non-peripheral, as a possible explanation of synesthesia. Such stimulation usually affects the peripheral origin of the nerve. If the ulnar nerve is struck at the elbow a diffused sensation occurs in hand and fingers. Similarly, if the optic nerve be stimulated along its path the light sensations would be referred to the eye, and yet distinguished from the visual perception of specks of external light. In D.'s case it was difficult to determine whether or not the photisms were thus referred. Her frequent remark: "I do not see it with my eye," does not exclude this reference since, with eyes closed, she actually did not "see" it, yet the colors could closely approximate the light sensations resulting from trunk stimulation of the optic nerve. In fact, from her general descriptions, a close similarity between sensations resulting from nerve path stimulation and the photisms seems very likely.

Imagery

The effect of imagery upon the phenomenon was tested by having D. image tones. She has what is generally called absolute pitch and can

readily image at will any tone to within a range of less than a quarter-tone. As check, she was asked, later, to hum the tone. In no case was the photism active, in spite of an attempt to see the color, following suggestive questions. If then, the corresponding tone was played, the photism was at once present. (Incidentally, this is proof that D.'s synesthesia is not associative. She knew the color wanted and could image the sound of the corresponding tone, yet could not "see" it until it was objectively presented.) Thus, when centrally initiated, the impulse does not carry over into the other sensory field.

When D. was asked for a description after some time had elapsed between objective presentation and her reproduction, the answer would almost invariably be negative and a repetition of the stimulus would be asked for. If, then, the stimulus was regiven, the typical reaction would follow immediately; and the vague, uncertain reaction of the image test compared with the definite, vivid, immediate and constant reaction to the objective test indicates clearly a fundamental difference between the image and the photism. From this it seems that an image of a synesthetic color does not exist and that synesthesia is a sensory reaction. It is not voluntary and cannot be created by imagination. In this respect it differs fundamentally from hallucinations and other allied forms of mental reaction, since it not only does not involve the higher mental faculties, but cannot even be induced by them. (D. is possessed of excellent imagery in various sense departments.)

On the other hand, the difference between the photism and an image of the color is probably similar to the difference between an objective color field and its imagery. I can picture red, but the image could never pass as a substitute for the sensation "red" when a uniform red field is visually present. This similarity is additional proof that true synesthesia is not imaginal association. In vividness and general character it approaches objective stimulation. How it differs from this is described under "Quality," and this dual limitation—on one side as non-imaginal, on the other side as non-peripheral—indicates a direct neural, but non-peripheral stimulation as the explanation of synesthesia.

Quality

Of particular interest and significance is the quality of the photism. In order to test this D. was asked to illustrate as best she could what she saw when tones were heard. Some illustrations were drawn with closed eyes, while the photism was still active; others were reproduced

from memory, immediately after tone-presence, and with frequent request for repetition of the stimulus. Before studying the Figures, the manner in which they were drawn should be considered, since it helps in their interpretation.

With pencil in hand, D. would draw aimlessly and very lightly, the procedure indicating definitely that the line demarcation was not clear. Upon being asked to explain why she drew so vaguely, she replied: "I cannot draw it clearly because the colors shade gradually into each other and are constantly changing. I cannot hold any fixed pattern because none is there." Accordingly, in reproducing the drawings (on a white-black scale instead of in colors) I have kept the original lines light, but the very contrast of black on white sharpens the definition much more than that actually seen. Each Figure, therefore, is to be understood as a momentary form of the photism with the lines vaguer than the printed form indicates. Only the general characteristics are to be considered constant.

The photisms may be described as formless fields of shifting color. There is no definite outline and the field is never of uniform hue. When more than one color is present, they "run into one another" gradually, at the same time constantly changing what contour they have. Many illustrations were made, none of which differed from the description just given and illustrated in Figs. 2 and 3. They were at times described as similar to "melting harlequin ice-cream." The pitch-interval is reflected in the photism by a more closely diffused color field for the narrow interval (second) and more clearly defined tone bands on a neutral background for the wide interval (ninth). The "apartness" of the tones, in the latter case seems to cause an "apartness" in the color-bands. In other words, the more clearly the separate tones were present to consciousness, the more clearly were separate bands of shifting color present in the photism. To some extent this is seen also in the other illustrations. Yet, we cannot be sure that this aspect was not induced by the desire to "reproduce" the photism. A similar difficulty exists in the localization aspect: right-side and left-side could be discerned after attention was directed to this feature, but from many observations made, did not function in the immediate photism.

Fig. 4 shows the effect of pitch on the delineations of the photism. The lines decrease in number and in complexity as the pitch rises. Other things equal, they may be said also to be fewer and simpler for single tones than for tone-combinations (see Fig. 5). This shift of colors is

mf
mf
3
f
p
2

FIG. 4

not the equivalent of the "beat-phenomenon" of discord. An octave, D. reports, shifts as much as a second (two reds, a light and a darker, for example, shift as much as a red and a green). Moreover, F♯ (orange and blue) shifts as much as do F and G (orange and blue), but for F♯ the changing lines "seem closer."

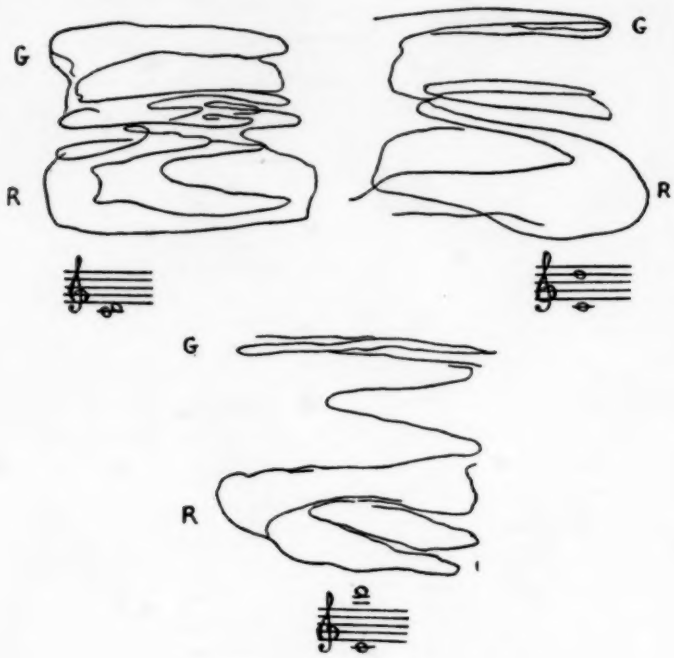

FIG. 5

This photismic movement, which was characteristic of all of D.'s synesthesiae, rules out extrinsic association as the cause of the phenomenon, but it also demands an explanation of why a constant primary stimulus, such as an organ pipe tone, produces an inconstant secondary stimulus. Some light is thrown on this problem by the results of a test for effects of a visual after-image on the photism. D. fixed her eyes sufficiently long on a colored surface to obtain an adequate after-image. When, thereupon, a tone of contrasting color was sounded, D. "saw" both colors: the after-image and the photism. "The red (C) is not where the green (after-image) is. I can see both but the green seems more objective." When we recall that nerve-trunk stimulation (such as

the ulnar nerve shock at the elbow) affects the peripheral organs, D.'s synesthesia cannot occur through stimulation along the nerve because no retinal sensation occurs. On the other hand, the "tingling" sensation of the ulnar nerve stimulation is an inconstant, vaguely localized sensation, as are the photisms. Again, when looking steadily at a perfectly clear blue sky, tiny black specks frequently pass aimlessly over the visual field. The movement is similar to the photismic movement. The conclusion seems possible, therefore, that the instability of the secondary sensation may result from circulation changes (or other chemical changes) in the extra-cortical or intra-cortical areas. When we consider the known subtle effects of the vasomotor system upon the blood-supply in the brain, effects on the photism seem plausible. A further support of such a theory is found in the action of certain drugs. Alcohol and haschisch have already been mentioned. I add a description of a subject under the influence of peyote (generally known as mescal), ". . . . and intermingled with the stars large orange and yellow nebulae moved in elliptical and circular orbits." "At first there was merely a vague play of light and shade . . . . mostly a vast field of golden jewels, studded with red and green stones, ever changing." The typical effect of the drug is described in the United States Dispensatory as follows: "produce a peculiar cerebral excitement, attended with an extraordinary visual disturbance, characterized by an incessant flow of visions of infinite variety, of both color and form."

If a "red" cortical area be stimulated synesthetically, a sensation of redness must result, but it is not the same as the red of a seen pigment or even that of an after-image because the retina has not been stimulated. The photism thus seems to result from stimulation of neurons from a direction other than the normal peripheral stimulation. It differs also from recall stimulation, since D. at least, could not create a photism through imagery, although she is above normal in imagination. This requires the possibility that cortical cells can be stimulated in three ways: by normal peripheral stimulation; by higher mental processes of memory, recall, and imagination; and finally, by stimulation of neighboring cells of another sense-department. Such interaction demands a spacial arrangement, or its cortical equivalent, from sensations resulting from a one-dimensional series. That is to say, the registration in the cortex for middle C would be closest to that for the two adjoining tones (B and C♯) and less close to that for the C an octave lower or higher. The

cortical registration for green would lie next to that for yellow and blue (adjacent colors in the frequency series).

Some evidence in support of this view is found in the localization of cerebral functions. The motor areas for eye, nose, mouth and vocal cords lie adjacent, as do those for fingers, hand and the arm (153).

When a pitch-frequency is given (A♭) that lies between two colors (blue and violet, G and A) that are already adjacent in both series (hence cortically adjacent?) the sensory-reflex is merged into a single color-sensation: a blue-violet. When, on the other hand, two widely separated pitch-frequencies awaken separated color frequencies two areas of irradiation occur without overlapping, resulting in two colors being present in the photism.

There are obvious difficulties in the way of such a cerebral localization theory: the octave-similarity of color, for example. In explanation of this we should have to assume common elements (octave partial). If we assume partials, can we eliminate all but the octave? And if we do not, the others, such as the third (interval of a twelfth) would introduce the other photismic color which is not present in the photism. The data at hand do not furnish enough facts to make this step of the analysis more than speculation.

CONCLUSIONS

1. Synesthesia is a secondary sensation in one sensory field produced by a primary stimulus in another sensory field.

2. The sensory reaction is affected by associative reactions.

3. It may be divided into two classes: sensory and associative. The associative class subdivides into two groups: intrinsic and extrinsic. The associative class alone—whether intrinsic or extrinsic, or both—is not synesthesia. This demands the presence of co-sensations, not merely co-images or co-ideas.

4. Synesthesia is an atypical phenomenon. It is not a normal neural reaction and is present in relatively few individuals.

5. Synesthesia is an individual phenomenon. Its elements vary with the individual and do not follow any general law in their concreteness. No two synesthetes show the same array of tones and colors. The associative aspects, on the other hand, are general.

6. In every case of sensory synesthesia, the intrinsic associations operate. The sensations determine the specific tone-color bonds; the

intrinsic associations, the bonds resulting from the general structure of the pitch and color series as wholes. The former is abnormal—the latter normal.

7. Synesthesia is closely associated with intelligence, imagination and sensitivity; in short, with a highly organized nervous system.

8. The probable basis for synesthesia is an interlacing of fibres, with modified synaptic conditions, either extra- or intra-cortical. The name sensory-reflex describes the phenomenon.

9. Photisms are not the result of peripheral optical stimulation. They are likewise not the result of chance (extrinsic) association.

10. Synesthesia has a tendency to deteriorate as the subject gets older. This may result from the fact that it serves no useful purpose in the life of the organism. When synesthesia is retained through years the original sensorial type is frequently reënforced with the associative type which helps the fixation but not necessarily the immediacy or vividness of the original sensory aspect.

11. Detailed localization of photisms is difficult and relatively indefinite. They are usually described (definitely so in the case of D.) as "within the head." The transfer of the high-low, right-left distribution to the photismic field varies, and is probably the result of an attention factor, and not of the immediate photism.

12. Photisms cannot be induced by imagery. They do not fuse with optical stimuli simultaneously present.

13. The quality of the photisms is a disordered, formless, but relatively smooth shifting of color bands or of a field of color. This shifting is independent of the constancy of the primary stimulus.

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OBSERVATIONS ON THE GROWTH, CLASSIFICATION AND EVOLUTIONARY SPECIALIZATION OF GIBBONS AND SIAMANGS

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CHAPTER I. INTRODUCTION

For the study of the inseparable problems of human evolution and of man's place among the primates we are still much in need of additional exact and detailed information in regard to apes and monkeys. According to all available evidence man and the three large apes constitute one small group of Old World primates, at least if contrasted with the extensive series of African and Asiatic monkeys. Between the latter and the few highest primates stand the gibbons and the siamang, forming the family *Hylobatidae*. Due to this intermediate position, the *Hylobatidae* play a very prominent rôle in all attempts to reconstruct the evolutionary history of the highest primates. The various gibbons and the siamang represent several evolutionary experiments (differing comparatively little in direction and in extent) which must have originated from the same ancestral stock which has given rise also to man. That many phases of these particular experiments in primate evolution have been at least as far-reaching in *Hylobatidae,* as other phases have been in the profound experiments leading to present-day man, is evident from the numerous extreme specializations peculiar to the gibbon family.

To include in one and the same paper observations on classification and evolutionary trends as well as those on growth may appear at first as unwarranted. It is, however, precisely such a combination of phylogenetic with ontogenetic studies which is very helpful for a proper understanding of many problems of growth *and* of evolution. Any specific, generic, or other taxonomic difference is due to some phylogenetic change which, primarily, can have affected nothing but the process of growth of the one or more bodily structures showing the change, the change appearing most clearly at the completion of growth.

A recent paper by the author (1930) on the skeleton of the trunk and limbs of higher primates contains many data bearing upon the problem of the subdivision of the family *Hylobatidae*. These particular data led to the following conclusion:

> At a number of places in this paper it has been pointed out that a much greater difference exists between the large siamang and any species of *Hylobates* than between any two of the latter. The characters showing such differences are collected in Table 36, which also contains the conditions in the small siamang. This long list of features of the skeleton of trunk and limbs alone, including many items in which the two ranges of variations do not overlap, fully justifies the generic rather than specific separation between the large siamang and the gibbons. . . . . There can be no doubt that *Symphalangus syndactylus* approaches the anthropoid apes, particularly the orang-utan, more closely than do the various species of *Hylobates*. The data in Table 36 show that *Symphalangus klossi* stands in general decidedly nearer to the gibbons than to the large species of its own genus. For this reason it seems quite likely that *S. klossi* should really either be moved into the genus *Hylobates*, or else should constitute a new genus of its own. Since the author was able to examine only two skeletons of *S. klossi* (besides a few immature, preserved specimens) he cannot insist on this proposed change in nomenclature.

Since this was published the author has been able to study a great amount of additional skeletal material, including specimens of "*S. klossi*." He has also examined and measured a large series of skulls of gibbons and siamangs. Furthermore, in the course of his comparative investigations on the growth of primates he has gradually accumulated notes and measurements on sixty-eight preserved bodies of the *Hylobatidae*. It is the purpose of this paper to bring together all these data on the skeleton, the outer body, and on the growth of gibbons and siamangs, and to compare briefly the conditions in the *Hylobatidae* with those in other catarrhine primates. Thus, it is intended to contribute new information not only for conclusions in regard to the proper position of *Hylobatidae* among catarrhines, but also for the classification of at least some of the different species within this family. In many instances these data reveal more or less definitely the evolutionary trends which have produced the various specializations of the gibbons and of the siamang.

It cannot be disputed that any classification becomes more reliable and justifiable the greater the number of different characters which have been considered, and the more specimens of a kind which have been examined. The frequent taxonomic procedure of laying main stress upon the color of the hair fails almost completely in attempting to sepa-

rate most of the species of the genus *Hylobates*. The members of this group are well known to manifest enormous individual variations in regard to hair color. This color, furthermore, changes frequently to a surprising degree with advancing age. In some instances this change proceeds from nearly white to very dark (e. g., *H. leucogenys*); whereas in other cases this order is reversed. In the Hopkins collection are nine adult female *Hylobates pileatus*, collected at one time and at one place (Ban Sadet, Siam); the limbs of eight of these specimens bear very light-colored hair, whereas the ninth has hair of an entirely black color. The infant of one of the light-haired mothers has much darker, reddish-brown hair. In speaking of *Hylobates nasutus*, Elliot (1913, III, p. 155) makes the following remarks in regard to the variability of hair color in the genus *Hylobates*:

> Two individuals of this species were received by the Zoological Society of London from Hainan in the jet black pelage, but when their coats were shed, one, the female, gradually assumed a white or silvery gray dress . . . . thus presenting a striking and an unanswerable evidence of the mutability of the coloring in the coats of members of this genus, and its worthlessness as a specific character, when the general hue of the dress is considered. . . . Uniformity of coloring is not one of the tenets of the species of *Hylobates*, and so far as the hues of their coats are concerned each one wears whatever seems best in his own eyes. The quantity and depth of color pigments among the members of the different species is a most uncertain quality, and rarely do two individuals possess them in the same degree, otherwise these many and extreme variations are quite unaccountable.

As will be shown later on, the skeletal characters of gibbons also vary to a very marked degree. The same is true in regard to body proportions. It is evident, therefore, that the division of the genus *Hylobates* into definable species represents an unusually difficult and laborious task, requiring an enormous mass of material. According to Elliot (1913) there exist 12 gibbon species, but according to Pocock (1927) only 3. Kloss (1929) recognizes 7 species of which two were assigned by Elliot and others to a separate genus. These three authors agree in regarding *H. hoolock*, *H. lar* and *H. concolor* as distinct species.

As shown by Table 1, the writer has accepted the first five species of *Hylobates*, listed by Kloss. For reasons to be referred to later, *H. leucogenys* and *H. pileatus* appear to differ as much from other gibbon species as any of the latter differ from one another, hence the view of Kloss, that they are mere subspecies (the former of *H. concolor* and the latter of *H. lar*), is not followed in this paper. Whether there exist still other species of true gibbons and whether the seven species adopted

TABLE 1

The Classification of the Family Hylobatidae According to Different Authors

ELLIOT, 1913	POCOCK, 1927	KLOSS, 1929	SCHULTZ
Genus HYLOBATES:	Genus HYLOBATES:	Genus HYLOBATES:	Genus HYLOBATES:
1. *H. nasutus*	1. *H. hoolock*	1. *H. hoolock*	A. Subgenus *HYLOBATES*
2. *H. hoolock*	2. *H. lar* (*H. leuciscus, H. agilis, H. pileatus, H. mülleri* = subspecies of *H. lar*)	2. *H. lar* (*H. entelloides, H. pileatus* = subspecies of *H. lar*)	1. *H. hoolock*
3. *H. lar* (= *H. entelloides*)	3. *H. concolor*	3. *H. cinereus* (= *H. leuciscus*) (*H. mülleri, H. funereus* = subspecies of *H. cinereus*)	2. *H. lar*
4. *H. henrici*		4. *H. agilis*	3. *H. leucogenys*
5. *H. leucogenys*		5. *H. concolor* (*H. henrici, H. leucogenys, H. gabrielli* = subspecies of *H. concolor*)	4. *H. cinereus* (= *H. leuciscus*)
6. *H. gabrielli*		6. *H. syndactylus*	5. *H. agilis*
7. *H. leuciscus*		7. *H. klossi*	6. *H. pileatus*
8. *H. agilis*			7. *H. concolor*
9. *H. pileatus*			B. Subgenus *BRACHITANYTES*
10. *H. concolor* (= *H. mülleri*)	("Only three definable species")		1. *H. klossi*
11. *H. funereus*			
12. *H. fuscus*			
Genus SYMPHALANGUS:	Genus SYMPHALANGUS:		Genus SYMPHALANGUS:
1. *S. syndactylus*	(not discussed)		1. *S. syndactylus*
2. *S. klossi*			

by the author are really *always* distinguishable, are questions with which this study cannot concern itself. It will be shown in detail, however, that whatever differences exist between the various forms of gibbons proper, they are not as marked as the total of the differences between any of these gibbons and *Hylobates klossi*. In the latter animal are found combined some of the characters of gibbons and some of the siamang, the former characters far outweighing the latter. For these reasons the author has been forced to the conclusion that the genus *Hylobates* must be divided into two subgenera (see Table 1). The subgenus *Hylobates* contains whatever species of true gibbons will finally be accepted. For the second subgenus, which is represented by the single species *H. klossi*, the author proposes the name *Brachitanytes* (= "arm-swinger"), a term which seems at least as appropriate in this family as *Hylobates* (= "tree-walker") or *Symphalangus* (= "one with joined digits").

Miller (1903), who first described *Hylobates klossi*, regarded it as "a dwarf siamang" and named it *Symphalangus klossii*. Kloss (1929) proposes to eliminate the entire genus *Symphalangus* and, therefore, names the species *Hylobates klossi*. The writer is of the opinion that the results of the present investigation amply justify the new position of this species as *Hylobates* (*Brachitanytes*) *klossi* (see also Schultz, 1932).

The accumulated new data fully confirm the conclusion in the author's last paper on this subject (1930) that the siamang should be retained in a separate genus within the family *Hylobatidae*. It is very significant that in almost all the new characters investigated the siamang stands clearly apart from the gibbons.

The sections *C* to *F* of Chapter 3 represent a revision and enlargment of those portions in the former paper by the author (1930) which deal with the corresponding structures in *Hylobatidae*. Since repetition had to be avoided, the reader must turn to the former paper for many of the basic data, the measuring technique, etc. relating to the skeleton of the trunk and limbs.

The author wishes to acknowledge with gratitude his indebtedness to the National Academy of Sciences for a grant to aid in the publication of this paper.

CHAPTER 2. MATERIAL

As shown by Table 2, the majority of the specimens studied belong to the division of mammals of the U. S. National Museum. The unusually large collection of gibbon material in this museum includes all the specimens of the rare *Hylobates klossi* available in this country. Besides the specimens appearing in Table 2, the author examined a few in still other collections, already listed in the tables of basic data in the

TABLE 2

List of the Collections Utilized for this Study, Abbreviations of the Names of these Collections in Subsequent Tables and in Illustrations, and Numbers of Specimens Used in the More Extensive Series

COLLECTION OF:	ABBREVIATION	NUMBER OF SPECIMENS STUDIED FOR:				TOTAL OF DIFFERENT SPECIMENS
		Skull	Spine	Limbs	Growth, etc.	
National Museum, Washington, D. C.	N. M.	56	32	19	22	83
Anatomy, Johns Hopkins University..	J. H.	..	1	11	26	26
American Museum of Natural History	A. M.	13	10	6	1	20
Adolph H. Schultz.....	A. S.	11	2	5	..	14
Anatomy, University of Zürich.....	A. Z.	..	..	..	12	12
Prof. E. Selenka.....	E. S.	..	..	..	3	3
Anatomy, Columbia University.....	A. C.	1	1	1	..	1
Wistar Institute of Anatomy.....	W. I.	..	..	..	1	1
Zoological Garden, Philadelphia.....	Z. P.	..	..	..	1	1
R. College of Surgeons, London.....	C. S.	..	..	1	..	1
Zoological Society of London.....	Z. L.	..	..	..	1	1
Museum of Natural History, Bern...	M. B.	..	1	..	..	1

first paper (1930). In the latter tables two corrections should be made: *"Symphalangus klossi"* should be changed to *Hylobates* (*Brachitanytes*) *klossi* and *"Hylobates leuciscus"* should be replaced by the earlier name of *Hylobates cinereus,* as pointed out by Kloss (1929).

All the skulls used in this paper are from fully adult animals with complete permanent dentition. The material discussed in the chapters

dealing with the outer body and with growth consists of preserved (mostly embalmed) specimens, whose sizes, approximate ages, etc. are recorded in the tables VI and VII.

For the generous permission to study the gibbon material in the collections listed in Table 2 the author is greatly indebted to his various colleagues in charge of these collections.

CHAPTER 3. SKELETON

A. Skull

a. Capacity

The cranial capacity was measured by means of mustard seed. Table 3 shows the results obtained by the author and those recorded in

TABLE 3

The Cranial Capacity (cu. cm.) in Hylobatidae According to some Data in the Literature and the Author's Measurements (See Tables I and II)

SPECIES	AUTHOR	SPECIMENS	AVERAGE	MIN.	MAX.
Hylobates lar	Oppenheim, 1912	4	94.7	70	130
	Oppenheim, 1912 ("*entelloides*")	4	94.7	89	100
	Schultz	20	98.5	84	118
	COMBINED...	28	**97.4**	70	130
Hylobates agilis	Oppenheim, 1912	8	103.1	81	120
	Schultz	13	96.2	86	111
	COMBINED...	21	**98.8**	81	120
Hylobates pileatus	Schultz	9	**93.7**	81	104
Hylobates concolor	Kirchner, 1895..	63	?	82	130
	Schultz	6	101.2	85	136
	COMBINED...	(69)	**101.2**	82	136
Hylobates cinereus	Oppenheim, 1912 ("*leuciscus*")	4	86.6	80	90
	Schultz	6	103.8	94	115
	COMBINED...	10	**96.9**	80	115
Hylobates hoolock	Schultz	3	**96.0**	93	100
Subgenus Hylobates	*AVERAGE*	77	**97.5**	70	136
Hylobates klossi	Schultz	10	**87.1**	78	103
Symphalangus syndactylus	Oppenheim, 1912	26	126.3	100	152
	Schultz	14	121.2	106	138
	COMBINED...	40	**124.6**	100	152

the papers by Kirchner (1895) and by Oppenheim (1912). In view of the enormous individual variations the apparent species differences in capacity can at best be of limited significance, except in the case of *Hylobates klossi* which possesses the smallest of all capacities. The maximum value (103 cu. cm.) of *H. klossi* far exceeds the minimum values of all the species in the subgenus *Hylobates* and lies even above the lowest value in *Symphalangus syndactylus*. In regard to the volume of the brain case the siamang is much farther removed from the subgenus *Hylobates* (average difference 27 cu. cm.) than is *Hylobates* (*B.*) *klossi* (average difference 10 cu. cm.). The total range of variations among adult *Hylobatidae* extends from 70 to 152 cu. cm., i. e., the highest value is more than twice as great as the lowest value.[1]

TABLE 4

The Body Weight (kg.) of Adult Hylobatidae According to Records in the Papers by Miller (1903), Weber (1904), Schneider (1905), Lyon (1907, 1908, 1911), and Pocock (1927)

SPECIES	SEX	SPECIMENS	AVERAGE	MIN.	MAX.	MEAN OF ♂ AND ♀
Hylobates lar	♂	4	5.1	4.3	5.6	5.2
	♀	1	5.3	..	..	
Hylobates agilis	♂	10	6.0	5.0	7.4	5.9
	♀	3	5.7	5.7	5.8	
Hylobates concolor	♂	10	5.6	4.9	6.8	5.7
	♀	11	5.8	4.6	6.8	
Hylobates cinereus	♂	4	6.3	5.9	6.5	6.1
	♀	2	5.8	5.6	6.0	
Hylobates hoolock	♂	5	6.9	6.0	7.9	6.7
	♀	2	6.5	6.4	6.6	
Hylobates klossi	♂	2	5.7	5.2	6.1	5.8
	♀	4	5.9	5.2	6.5	
Symphalangus syndactyl.	♂	5	11.1	9.5	12.7	10.7
	♀	5	10.2	9.0	11.6	

[1] The values in Table 3 agree very closely with those mentioned recently by Sir Arthur Keith (1931, fig. 13): Cranial capacity of Gibbon = 95 cu. cm. (range 80-140) and of Siamang = 125 cu. cm. (range 110-150).

The size of the brain or of the cranial capacity is of interest chiefly in its relation to the size of the entire body. It is a well established rule that in general the brain is proportionately the larger the smaller the body. In a house cat, e. g., the weight of the brain forms 0.94 per cent of the body weight, whereas in a lion only 0.18 per cent. In primates this percentage relation is according to Dubois (1914) 3.82 in a marmoset, weighing 0.335 kg.; 1.37 in a siamang, weighing 9.5 kg.; 0.54 in an orang-utan, weighing 73.5 kg.; and 2.18 in adult white man. To these figures the author can add the relative brain weight of 1.96 per cent in an adult *Hylobates lar,* weighing 4.485 kg. Corresponding to its lesser size, therefore, the gibbon possesses a considerably higher relative brain weight than does the siamang.

The body weights of adult *Hylobatidae* in Table 4 have been collected from various sources. Since the brain weight (in grams) corresponds roughly to the cranial capacity (in cubic centimeters) one can substitute the latter for the former in calculating at least an approximate brain size in relation to body weight. Thus, the averages in Table 3 have been expressed in percentage of the corresponding averages (for ♂ and ♀) in Table 4, according to the formula:

$$\frac{\text{cranial capacity (cu. cm.)}}{\text{body weight (g.)}} \times 100$$

The following approximate relative capacities have been obtained by this method:

Hylobates lar	= 1.87	*Hylobates hoolock*	= 1.43
Hylobates agilis	= 1.67	Average of subgenus *Hylobates*	= 1.67
Hylobates concolor ..	= 1.78	*Hylobates* (*B.*) *klossi*	= 1.50
Hylobates cinereus ...	= 1.59	*Symphalangus syndactylus* ...	= 1.16

Again it is found that the large siamang has a relatively smaller cranial capacity than have the gibbons, a result which was to be expected. It is surprising, however, that *Hylobates* (*B.*) *klossi* does not possess a relative capacity at least equal to that of the gibbons proper. According to Table 4, *H. klossi* is on an average heavier than *H. lar,* as heavy as *H. concolor* and *H. agilis,* but not so heavy as *H. cinereus* and *H. hoolock.* These average weights, however, are of only limited significance. They are based upon relatively few specimens and the individual weight can be influenced to a considerable extent by the amount of food the animal consumed shortly before its death.

That the average relative cranial capacity of gibbons (1.67) surpasses that of lower catarrhines of equal size is indicated by the following figures: in an adult female *Pithecus rhesus* (P. A. L. 21), weighing 5960 g., the capacity measures 85 cu. cm. or only 1.43 per cent of the body weight.

b. Absolute and relative dimensions

The author has taken a great many different measurements on the skulls of gibbons and siamangs in an attempt to find the particular ones which, in their interrelations, show most clearly the characteristic species differences. The following eight measurements have finally been selected as the few most useful ones for distinguishing some of the members of the *Hylobatidae*:

1. Skull length = maximum mid-sagittal length of brain case from *glabella* (*D*, fig. 1.).

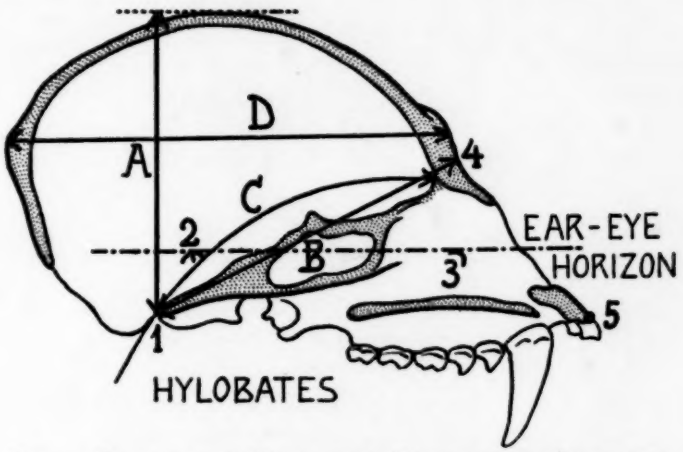

FIG. 1. DIAGRAMMATIC MID-SAGITTAL SECTION OF THE SKULL OF A GIBBON, SHOWING SOME OF THE MEASURING POINTS AND MEASUREMENTS

1 = *basion* (Mid-sagittal point of anterior border of *foramen magnum*); 2 = porion (middle of upper edge of *porus acusticus externus*); 3 = *orbitale* (deepest point on lower border of left orbit); 4 = *nasion* (mid-sagittal point of nasofrontal suture); 5 = *prosthion* (most anterior mid-sagittal point on alveolary border between middle incisors); *A* = Skull height; *B* = Base length; *C* = Inner base length (measured as straight distance between the end points of the arc); *D* = Skull length.

2. Glabellar thickness = thickness of frontal bone beneath *glabella*, obtained by deducting the straight distance from *basion* to most anterior point of brain cavity (*C*, fig. 1) from the base length (*B*, fig. 1).
3. Skull breadth = maximum breadth of brain case, situated between the *squamae temporales*, but not on the crests above the ear openings (*A*, fig. 2).

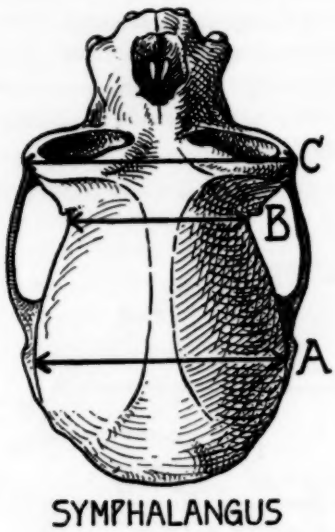

FIG. 2. TOP VIEW OF THE SKULL OF A SIAMANG SHOWING THE FIRST THREE BREADTH DIMENSIONS

A = Skull breadth; *B* = Postorbital breadth; *C* = Biorbital breadth.

4. Skull height = projective height of brain case from *basion* to vertex, perpendicular to ear-eye horizon (*A*, fig. 1). The ear-eye horizon is the best and generally accepted plane of orientation, determined by the two *porion* points and the left *orbitale* (2 and 3, fig. 1).
5. Postorbital breadth = minimum breadth of brain case behind the orbits (*B*, fig. 2).

6. Biorbital breadth = maximum breadth between the frontal processes of the zygomatic bones (*C*, fig. 2).
7. Palate length = from *prosthion* (5, fig. 1) to middle of line connecting the most posterior points on the alveolary processes (*A*, fig. 3).
8. Palate breadth = maximum breadth between the alveolary processes, perpendicular to palate length (*B*, fig. 3).

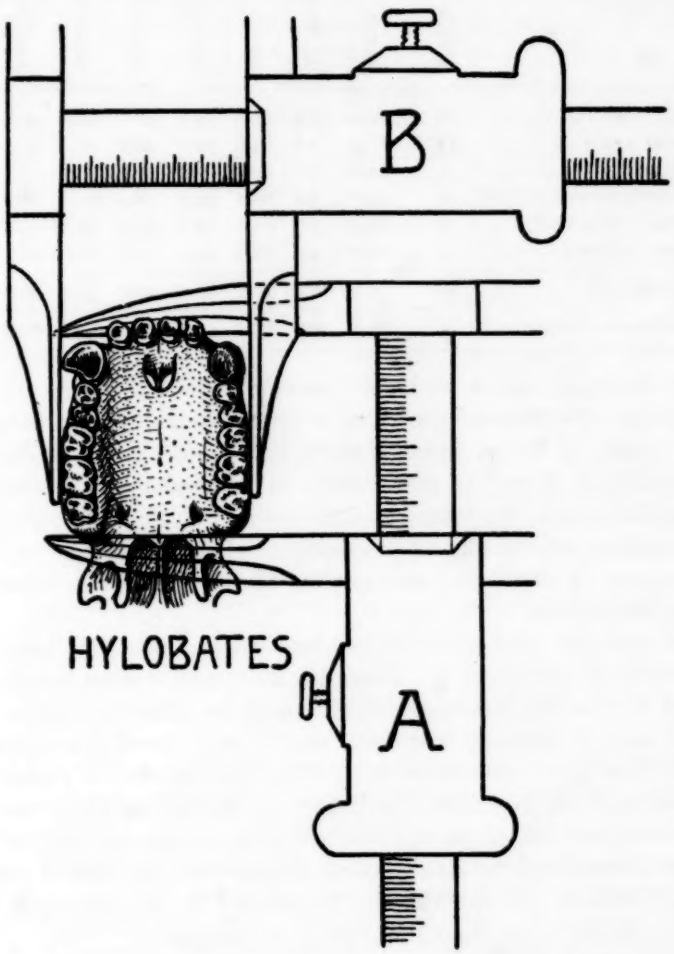

FIG. 3. POSITIONS OF SLIDING COMPASS IN MEASURING *A* = PALATE LENGTH AND *B* = PALATE BREADTH

TABLE 5

Averages of the Absolute Dimensions of the Skulls of Adult Hylobatidae Listed in the Tables I and II

SPECIES	SPECIMENS	SKULL LENGTH	GL. THICKNESS	SKULL BREADTH	SKULL HEIGHT	POSTORBITAL BR.	BIORBITAL BR.	PALATE LENGTH	PALATE BREADTH
Hylobates lar	20	79.9	3.3	62.0	54.0	48.1	62.9	40.1	32.3
Hylobates agilis	13	81.4	3.8	60.9	52.4	46.8	63.4	39.5	33.2
Hylobates pileatus	9	81.2	2.7	60.1	51.7	46.4	61.9	38.3	32.4
Hylobates concolor	6	79.7	3.2	63.0	53.5	48.2	62.8	40.7	33.0
Hylobates cinereus	6	83.5	3.3	61.8	53.7	46.8	62.5	41.0	32.7
Hylobates hoolock	3	79.3	3.3	62.3	51.3	48.7	65.0	40.7	32.7
Hylobates klossi	10	75.6	1.6	57.6	52.2	44.6	58.3	36.8	30.4
Symphalangus syndact. ..	14	90.8	8.0	65.4	55.1	47.1	70.3	52.9	41.0

The average values of these measurements (in mm.) are listed in Table 5. The average skull length varies around 80 mm. in the different species of the subgenus *Hylobates,* it is nearly 5 mm. shorter in *H. klossi,* and almost 11 mm. longer in the siamang. According to Oppenheim (1912) the same measurement averages in 26 siamangs 90.2 mm., ranging individually to a maximum of 97 mm. The maximum skull length of *Hylobates* amounts to 88 mm. and was found in a female *H. cinereus.*

The glabellar thickness averages nearly two and a half times more in siamangs than in gibbons. There are no frontal sinuses in any *Hylobatidae,* so that the enormous thickening of the glabellar region of the frontal bone in siamang is entirely due to an unusual development of diploë. The great difference in skull length between *Hylobates* and *Symphalangus* is, therefore, due largely to this difference in the thickness of the bone behind the anterior end point of the skull length.

The averages of the skull breadth differ relatively little in the various *Hylobatidae.* In the siamang it amounts to 65.4 mm. but in the Bornean gibbon to not much less, namely to 63.0 mm.

The skull height is even more uniform than the skull breadth, the averages varying only between 51.3 and 55.1 mm. It is very interesting

to find that the small skull of *Hylobates klossi* is actually higher than the skulls of *H. hoolock* and of *H. pileatus*. The skull of the large siamang is only 1.1 mm. higher than that of *H. lar*. According to Oppenheim (1912, measurement No. 12) the skull height of the siamang is even shorter, averaging in 26 specimens only 53.6 mm.; i. e., the same as in her 8 *Hylobates agilis* (53.5 mm.) and less than in the writer's *H. lar* and *H. cinereus*. It can already be stated, therefore, that *H. klossi* possesses a relatively high skull and *S. syndactylus* a proportionately low one. This is evident also from the drawings in figure 4.

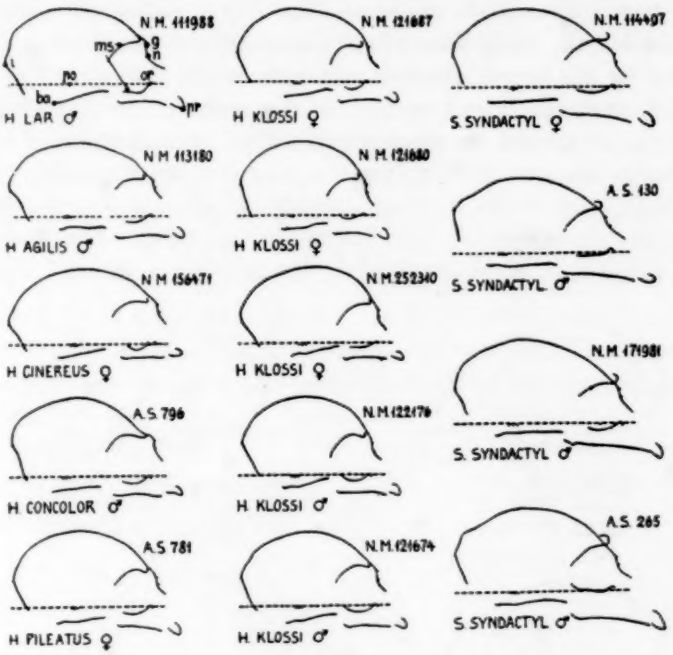

FIG. 4. MID-SAGITTAL SECTIONS OF SKULLS OF ADULT GIBBONS AND SIAMANGS, ORIENTED ACCORDING TO EAR-EYE HORIZON (BROKEN LINES)

Projected on these sections is shown the exact position of the left *porion* (*po*) and of the sagittal section through the middle of the left orbit (*ms*). *g = glabella; n = nasion; or = orbitale; pr = prosthion; ba = basion; i = inion* (for explanation of these craniometric terms and of the methods for constructing these drawings with the diagraph see Martin, 1928).

The averages of the postorbital breadth, as those of the last measurement, show a maximum difference of only about 4 mm. The mean of the averages in the subgenus *Hylobates* amounts to 47.5 mm., the average of *Symphalangus* is 47.1 mm. The constriction of the brain case behind the orbits is, therefore, more pronounced in the large siamang than in the average gibbon.

The biorbital breadth, on the other hand, is very much greater in the siamang than in any of the gibbons. The maximum individual value of this dimension is 69 mm. in a gibbon, whereas 77 mm. in a siamang.

The most marked differences between the skulls of *Symphalangus* and of *Hylobates* exist in the dimensions of the palate, particularly in the palate length. This measurement averages anywhere from 38.3 to 41.0 mm. in the latter, whereas 52.9 mm. in the former. The same dimension averages even 53.9 mm. in the series of 26 *Symphalangus syndactylus* measured by Oppenheim (1912, measurement No. 55). According to the same author (measurement No. 56) the palate breadth averages 41.7 mm. in her series of siamangs, which is also slightly higher than the corresponding average, obtained by the writer. That the palate of the siamang is disproportionately large, when compared with the

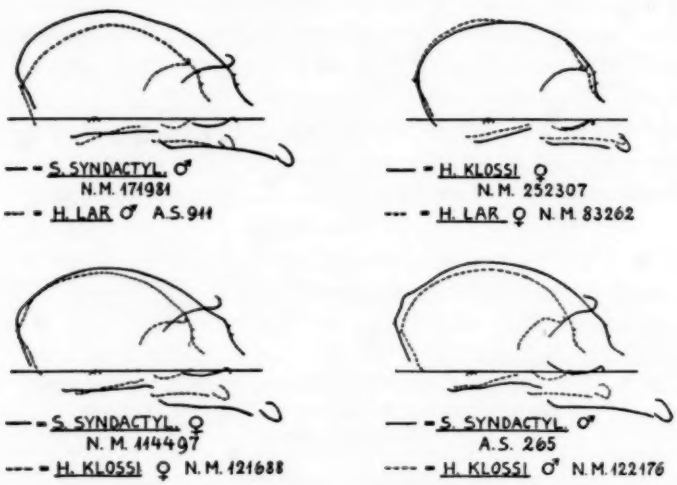

FIG. 5. MID-SAGITTAL SECTIONS OF SKULLS OF ADULT GIBBONS AND SIAMANGS (AS IN FIG. 4) SUPERIMPOSED SO THAT THE EAR-EYE HORIZONS AND THE LEFT PORION POINTS COINCIDE

palate in gibbons, was already known to Giebel (1880), who mentioned the fact in his brief paper. This difference is also clearly shown by the comparisons in figure 5 and by the skulls of a gibbon and of a siamang in figure 6. From these figures it is also evident that the great length of the palate causes the entire facial portion of the skull to project much farther forward in the siamang than in the gibbon.

In *Hylobates* (*Brachitanytes*) *klossi* the dimensions of the palate are considerably shorter than in any of the species of the subgenus *Hylobates*. The same difference has been found to exist in every other cranial measurement (and in the capacity), except in the skull height.

Absolute dimensions serve primarily to show only differences in size, but are not well suited to reveal the much more significant differences in shape, as expressed by the percentage relation between two measurements. Such relative measurements, or indices, have, therefore, been calculated from the eight absolute measurements discussed above. Five of the many possible indices have been selected as the most expressive ones for *Hylobatidae*. They are listed individually in the appended tables I and II and the average values are given in Table 6.

The proportion between the skull height and length is markedly different in the two genera. In the siamang the height amounts on an average to only 60.6 per cent of the length, in *Hylobates* (*Brachitanytes*) *klossi* to 69.1 per cent. In the former the index ranges between 56.5 and

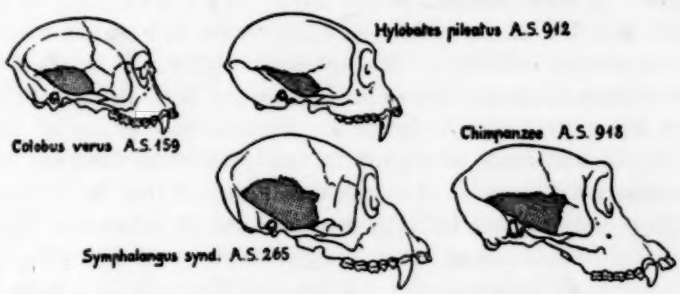

FIG. 6. SIDE VIEWS OF SKULLS OF A CATARRHINE MONKEY, A GIBBON, A SIAMANG, AND AN ANTHROPOID APE SHOWING THE RELATIVE SIZE OF THE SQUAMOUS PORTION OF THE TEMPORAL BONE (DOTTED AREA)

The skulls are oriented in the ear-eye horizon. The chimpanzee skull has been reduced to the same size as the siamang skull (drawn with dioptrograph).

TABLE 6

Averages of the Relative Dimensions or Percentage Proportions of the Skulls of Adult Hylobatidae, Calculated From the Figures in the Tables I and II

SPECIES	SPECIMENS	SKULL HEIGHT / SKULL LENGTH	POSTORBITAL BR. / BIORBITAL BR.	BIORBITAL BREADTH / SKULL BREADTH	PALATE LENGTH / SKULL L. — THICKN.	PALATE BREADTH / SKULL BREADTH
Hylobates lar	20	67.6	76.6	101.5	52.4	52.1
Hylobates agilis	13	64.4	74.0	104.2	50.9	54.5
Hylobates pileatus	9	63.7	75.0	103.1	48.8	54.0
Hylobates concolor	6	67.1	76.7	99.8	53.2	52.4
Hylobates cinereus	6	64.4	75.0	101.2	50.9	52.9
Hylobates hoolock	3	64.8	75.3	104.4	53.5	52.4
Hylobates klossi	10	69.1	76.6	101.2	49.7	52.8
Symphalangus syndact. ..	14	60.6	67.1	107.6	63.9	62.8

63.7, whereas in the latter between 66.7 and 72.0. The two ranges, therefore, do not overlap, so that the two types of skulls can be distinguished by their relative height alone. This difference in relative height is not due to any noteworthy difference in absolute height, but is caused almost entirely by the enormous difference in skull length. This is evident from the figures in Table 5 and is also clearly shown by the two lower drawings in figure 5. The various species of the subgenus *Hylobates* stand in regard to this proportion between the two just mentioned extremes. It is interesting to find that *H. lar* possesses the highest index within its subgenus, whereas *H. pileatus* is characterized by the lowest index, even though Pocock and Kloss regard the latter as a mere subspecies of the former. As will be shown in the chapter on limb bones (Table 16), the two species represent opposite extremes within the subgenus *Hylobates* also in regard to their intermembral indices.

The postorbital breadth in percentage of the biorbital breadth averages from 74.0 to 76.7 in *Hylobates* (with no principal difference between the two subgenera), whereas only 67.1 in *Symphalangus*. The

lowest individual value is 61.8 (*S. syndactylus*), the highest 85.0 (*H. hoolock*). This index was found to rise above 70 in only one of the 14 siamangs, but in 65 of the 67 gibbons. There exists, therefore, a very definite generic difference in this character, according to which the brain case behind the orbits is much more constricted in the siamang than in the gibbon.

That this difference is chiefly due to the great development in breadth of the orbits in the siamang, is shown by the percentage relation between the biorbital breadth and the skull breadth. This proportion averages 107.6 in *Symphalangus,* whereas only 99.8 to 104.4 in *Hylobates.* There exists an even more striking generic difference in the development in height of the orbit. As shown by the figures 4 and 5, the middle of the supraorbital arch projects in the siamangs far beyond the midsagittal profile of the frontal bone, whereas in gibbons this arch rarely rises above, or in front of, the supraglabellar region. These relations are difficult to see directly on the skulls, but are very clear and constant in the accurate drawings of the superimposed, parallel, sagittal sections.

To show to best advantage the comparatively great length of the palate in the siamang, this length is expressed in percentage of the skull length *minus* the glabellar thickness, which is also so great in this primate. This proportion differs most strikingly in the two genera, since it averages 63.9 in *Symphalangus* and only 48.8 to 53.5 in *Hylobates.* The ranges of variations do not overlap, since they extend from 45.6 to 58.7 in the gibbons and from 60.3 to 68.3 in the siamangs.

The palate breadth, expressed in percentage of the skull breadth, averages 62.8 in *Symphalangus* but only 52.1 to 54.5 in the various species of *Hylobates.* The ranges of variations reach in the latter from 47.5 to 60.3 and in the former from 56.7 to 68.9. Even though these ranges do overlap, the palate breadths differ in the two types very significantly, since only three siamangs were found to have indices below 60, whereas in 66 out of 67 gibbons this index amounted to less than 60.

The relative dimensions of the palate of *Hylobates* (*Brachitanytes*) *klossi* fall within the range of the corresponding averages of the various species in the other subgenus. To be exact, the former species has in proportion to its brain case the second shortest and fourth narrowest palate of all the *Hylobatidae.* It can now be stated that in the five cranial proportions of *Hylobatidae* the siamang furnishes invariably one extreme, whereas *H. klossi* represents just the opposite extreme in re-

gard to relative skull height and stands not far from the opposite extremes in the other four indices. A careful study of the figures 4 and 5 illustrates clearly the conclusion that in regard to the skull there exist much smaller differences between the subgenera *Brachitanytes* and *Hylobates* than between the genera *Hylobates* and *Symphalangus* (compare particularly the two upper drawings in fig. 5).

The outstanding distinctions between the skulls of siamangs and of gibbons are: (1) the brain case of *Symphalangus* is much larger than that of *Hylobates*, but the palate of the former surpasses in size that of the latter to an even greater degree; (2) the skull of the siamang is proportionately lower than that of the gibbon; (3) the postorbital constriction is more pronounced in the former than in the latter; (4) the orbits of the siamang project unusually far in a lateral and in a vertical direction; (5) as shown by figure 5, there is little, if any, generic difference in the length of the portion of the skull behind the ear openings, but the preauricular skull projects in the siamang far beyond the facial profile of gibbon skulls. This means, of course, that the ear openings are situated farther back in the former than in the latter; (6) the figures 4 and 5 illustrate the observation that the *foramen magnum* in the gibbon is directed downward, whereas in the siamang it rather tends to point backward. In consequence of this difference the ear-eye horizon extends through the middle of the foramen in most siamangs, but lies entirely above this foramen in gibbons.

It is very interesting and suggestive that in regard to all the points enumerated the adult gibbon skull resembles very closely the juvenile phase of the siamang skull (see, e. g., figs. 4 and 6 in the paper by Oppenheim, 1912). Infantile skulls of the two genera show as yet but little difference, but the ontogenetic changes in the skull of *Symphalangus* appear to be more far-reaching than in that of *Hylobates*. In many respects these extra changes carry the former in a direction toward the cranial conditions in the orang-utan.

c. Squamous portion of temporal bone

In a former paper the author (1915) has demonstrated that the squamous portion of the temporal bone participates to a larger extent in the formation of the lateral wall of the cranial vault in higher than in lower primates. In the course of his examination of the present series of skulls the author became convinced that in general the siamang possesses a relatively much larger *squama temporalis* than the gibbon.

Unfortunately, this can be seen, as a rule, in only the sub-adult specimens, since the *sutura squamosa* becomes obliterated rather early in the *Hylobatidae*. According to most of the skulls in which this suture could still be traced the *squama* of the gibbons is of approximately the same relative size as that of the lower catarrhines, whereas the *squama* of the siamangs is proportionately larger, being at least equal in size to the *squama* of the anthropoid apes (see fig. 6).

d. Sagittal crest

It has been shown that the palate and, therefore, the entire dental apparatus of the siamang is larger than that of the gibbon and this not only in absolute size but also in relation to the size of the brain case. For this reason it is to be expected that the siamang has also proportionately larger temporal muscles than the gibbon. These, in turn, would require a relatively larger surface for attachment in the former than in the latter. Upon examination it is actually found that the temporal lines on the skull approach one another much more closely in *Symphalangus* than in *Hylobates*. The smallest distance between the temporal lines amounts to anywhere from 15 to 40 mm. in gibbons, whereas to only 0 to 20 mm. in the siamangs. In two of the fourteen adult siamangs, examined by the author, the temporal lines do not only actually meet one another, but they form in addition a low mid-sagittal crest on the posterior half of the frontal arc and, continuing, along the anterior half of the parietal arc. The temporal lines in these two male skulls meet the end points of this crest, which is directly comparable to the (much larger) mid-sagittal crest in male orang-utans and gorillas and which serves to increase the surface area for the attachment of temporal muscles, too large for the cranial vault alone. In several other male siamangs the temporal lines approach one another to as little as 2 and 3 mm. There was no crest nor a very close approach of the temporal lines in any of the 67 skulls of adult *Hylobates* examined.

e. Cranio-pharyngeal canal

While measuring the present series of adult skulls of *Hylobatidae* the author recorded the presence and size of a persisting cranio-pharyngeal canal, which penetrates the basisphenoid bone in the mid-sagittal plane. No attempt was made to search for such incomplete canals in which only the upper portion, opening in the *sella turcica*, persists. The results are listed in Table 7 which contains also some comparative data

TABLE 7

The Cranio-pharyngeal Canal in Adult Hylobatidae and, for Comparison, in Other Catarrhine Primates. Cases in Which Only the Upper Opening of the Canal is Retained Have Not Been Considered. The Paper by Schlaginhaufen Includes Data Quoted From Maggi and From Waldeyer

SPECIES (OR GROUP OF SPECIES)	SPECIMENS	CANAL			PRESENT IN PER CENT OF CASES
		Small	Medium	Large	
Subfamily *LASIOPYGINAE* (Schultz, 1916)	123	1	1	..	2
Subfamily *COLOBINAE* (Schultz, 1916)	28	2	4	..	21
Hylobates lar	20	3	1	..	20
Hylobates agilis	13	3	1	..	31
Hylobates pileatus	9	4	..	..	44
Hylobates concolor	6	1	2	1	67
Hylobates cinereus	6	2	..	..	33
Hylobates hoolock	3	1	..	1	67
Total Subgenus *HYLOBATES*	57	14	4	2	35
Hylobates klossi	10	3	3	3	90
Symphalangus syndactylus	14	8	1	..	64
Genus *PONGO* (Schlaginhaufen, 1907; etc.)	66	..	..	..	24
Genus *PAN* (Schlaginhaufen, 1907; etc.)	33	..	..	..	67
Genus *GORILLA* (Schlaginhaufen, 1907; etc.)	53	..	..	..	43
Genus *HOMO* (Schultz, 1916)	771	27	2	2	4

for other catarrhine primates, collected partly from papers by other authors and partly from the writer's own observations, published in 1916. This canal is found most frequently in *Hylobates klossi,* since it is present in 9 out of the 10 skulls examined. In three of these cases the canal is wide open throughout its course. In the siamang a canal occurs in two thirds of the specimens but is, as a rule, very small. In the subgenus *Hylobates* this embryonic feature persists on an average in 35 per cent of adult skulls, large canals being very rare. All these

frequencies in *Hylobatidae* are very high, when compared with the frequencies of this canal in adults of lower catarrhines, particularly the *Lasiopyginae*. In the latter subfamily a complete canal was found in only one of 123 adult skulls examined. In all anthropoid apes a persisting cranio-pharyngeal canal is very common, particularly in chimpanzees. This has recently been confirmed by Cave (1931) who found the canal in 64 per cent of chimpanzees, in 35 per cent of gorillas, and in 14 per cent of orang-utans. Without giving any supporting data Cave claims that age has no bearing upon the incidence of the canal. In contrast to this, the writer (1916) found that partly obliterated canals occur in man in 31 per cent of juveniles and in only 8 per cent of adults. Complete canals were present among 307 monkeys in 10.8 per cent of juveniles but in only 3.6 per cent of adults. In man complete canals have been recorded in 0.5 per cent of 771 adults and, according to the data compiled by Cave, in even only 0.2 per cent of nearly 5,000 adults. Among older human fetuses and young infants, however, Limson (1932) discovered large and complete canals in 3.7 per cent of the cases. There can be no doubt, therefore, that this canal is much more common among young than among old primates.

A complete or partly obliterated cranio-pharyngeal canal in adult primates is very rare in platyrrhines (Schultz, 1916), in the catarrhine subfamily of *Lasiopyginae,* and in man. In the *Colobinae* the canal occurs somewhat more frequently. The gibbons, siamangs, and the three large apes are the only primates in which this canal is very common. This may be regarded as an additional, although not very significant, reason for assuming a close relationship between the *Hylobatidae* and the *Pongidae*.

f. Mandible

This discussion of the mandible will be restricted to the most characteristic difference between the two subgenera of *Hylobates* and between the two genera of *Hylobatidae*. These differences exist in the formation of the chin, i. e., of the mandibular symphysis.

Chasen and Kloss (1927) in speaking of *Hylobates klossi* state: "On the general configuration of the skull this gibbon could be referred to either *Hylobates* or *Symphalangus*. It resembles the latter in that the mandibular symphysis is rather more vertical than in the typical gibbons, . . ." In a later paper Kloss (1929) repeats this statement and mentions among remarks on the characters of *"Hylobates syndac-*

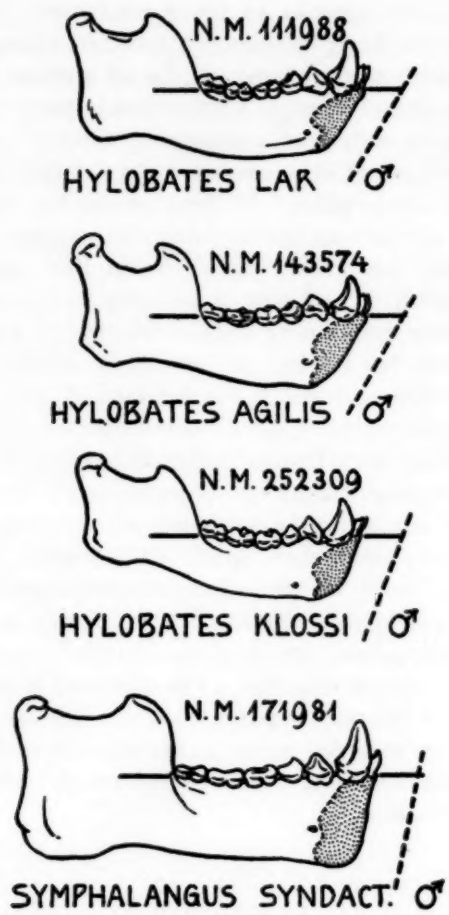

FIG. 7. RIGHT SIDE VIEWS OF MANDIBLES PROJECTED ON MID-SAGITTAL PLANE (DRAWN WITH DIOPTROGRAPH; DOTTED SYMPHYSEAL SECTIONS DRAWN WITH DIAGRAPH)

Horizontal lines = alveolary horizon; broken lines = direction of symphyseal profile.

tylus" that "in the skull the chin is only more pronounced and the mental symphysis and the profile of the ascending ramus only more vertical" than in "the more typical species" of *Hylobates*.

These differences are illustrated by the examples in figure 7. In the great majority of the gibbons of the subgenus *Hylobates* the chin is receding so that the profile of the symphysis forms a comparatively small angle with the alveolary horizon. In *Hylobates* (*Brachitanytes*) *klossi* this angle is somewhat larger, but not as large and as nearly a right angle as in *Symphalangus syndactylus*. The chin of the latter is less receding than in any other primate, except man.

According to the rather variable features of the ascending ramus, *Hylobates* (*B.*) *klossi* represents one extreme of an uninterrupted range of variations extending through the typical gibbons to the siamang at the opposite extreme. In the siamang mandible the unusually broad ramus stands nearly or entirely perpendicular to the body of the jaw, a condition found but rarely in gibbons.

B. Teeth

Congenital variations in the number of teeth in the *Hylobatidae* are of special interest in connection with the generic difference in relative size of the jaws. No such variations have been observed in any but the molar teeth. A reduction in the number of molars has never been described, nor has it been seen by the author, in any siamang. On the other hand, Giebel (1855) reports the case of a *Symphalangus syndactylus* with a fourth molar in the lower jaw, and the author possesses a skull (A. S. 265, ♂) of the same species which also has a well-developed fourth molar on the right side of the lower jaw.

In *Hylobates* supernumerary molars have been found in only one instance, namely by Kirchner (1895) in a male *H. concolor*, which had four molars on each side of the upper jaw. According to the same author the third molar was congenitally lacking on one side in two out of 68 adult *H. concolor* (once in upper jaw and once in lower jaw). In the writer's material of 68 adult *Hylobates* (including 11 *H. klossi*) the lower third molars are completely lacking in a male *H. agilis* (N. M. 114499). The right upper $M3$ of this specimen is reduced to a mere peg composed of two minute cusps and one root. In another male, *H. agilis* the lower left third molar is equally degenerated, the greatest diameter of its crown measuring barely 3 mm. A less extreme, but nevertheless pronounced, reduction in size and in number of cusps and

of roots is frequently encountered in the last molars of *Hylobates.* Kirchner (1895), having made the same observation on his extensive material of *H. concolor,* concludes: "Der III. Molar zeigt eine Reduction in der Höcker- und Wurzelzahl und zwar besonders im Oberkiefer, so-dass man annehmen muss, dass er auf den Aussterbeetat gesetzt ist." Duckworth (1915) also states that in the gibbon "the third molar tooth bears signs of degeneration." Finally, in the recent and very thorough investigation of the molars of orang-utan and of gibbon Eckardt (1930) finds that in *Hylobates* the third molars are (in exact translation) "in most cases subjected to a far-reaching reduction which effects in the upper jaw mostly a disappearance of the distal cusp or its extremely poor formation." Incidentally, in this same detailed study Eckardt describes many significant generic differences between *Hylobates* and *Symphalangus* in regard to the exact morphological conditions of the molar teeth.

It seems very significant that in *Hylobates,* with its proportionately small jaws, a fourth molar occurs in only one of 136 skulls (combined material of Kirchner and of Schultz), but congenitally absent third molars in three skulls and degenerate third molars in a great many other skulls. In the comparatively large jaws of *Symphalangus,* on the other hand, the third molars have never been found to be congenitally absent, but fourth molars occur in two out of 15 skulls.

These data support the assumptions that the tooth row of *Hylobates* tends to become shortened by the gradual elimination of the last molars, as in *Ateles* and in *Homo* (Schultz, 1925), whereas in *Symphalangus* the opposite trend seems to prevail. This trend consists in the lengthening of the jaws, thereby providing room for the addition of fourth molars. The latter teeth are fairly common not only in the siamang (13 per cent of 15 skulls), but also in some other primates with long jaws, for instance, in 4 per cent of 112 baboon skulls (Shaw, 1927) and in 20 per cent of 194 orang-utan skulls (Selenka, 1898).

In view of the great scarcity of authentic data on the ages at which the teeth erupt in *Hylobatidae,* it seems desirable to record here the developmental stage of the dentition in two gibbons of known age. These two captive-born specimens are brothers, aged one month and 22 months respectively, and belong to the species *Hylobates leucogenys* (N. M. 256087 and 256088).[2] In the baby of exactly 29 days only the

[2] For sitting heights, etc., of these specimens see Table VI.

two upper middle and the four lower milk incisors have erupted. According to Spiegel (1929) the same teeth have appeared 26 days after birth in a female Java macaque. According to the author's observations on macaques (*Pithecus rhesus*), born in the Carnegie Colony, the ages at which these first six deciduous teeth have appeared can vary considerably, as is shown by the following examples: ♀ (No. 72) = 18 days; ♀ (No. 73) = 21 days; ♀ (No. 50) = 21 days; ♂ (No. *J*) = 28 days; ♂ (No. *H*) = 42 days; ♂ (No. *G*) = 48 days; average age in the six specimens = 30 days. In a chimpanzee, born in the Philadelphia Zoological Garden, the upper middle and three of the lower incisors were all the deciduous teeth which had erupted when the animal died at the age of six months and 12 days (Schultz, 1930). According to Brandes (1928) the last of the upper middle and the lower incisors (as well as the first lower milk molars!) erupted in a captive-born orang-utan at the age of six months and 25 days. It can be stated, therefore, that the first six deciduous incisors appear in the gibbon as early as in the macaque (1 month) and much earlier than in the anthropoid apes (6 to 7 months) and man (6 to 12 months). It is quite possible, of course, that the age of eruption of these teeth varies in the gibbon at least as much as it does in the macaque. This is made probable by the brief statement by Robinson (1925) concerning a *Hylobates lar*, born in the Rangoon Zoological Garden. This "gibbon which died within six weeks of its birth had four incisors at the time of its death." In Brandes' orang-utan four incisors (and no other teeth) were present at the exact age of five months.

The second young gibbon has at the age of 22 months all of its milk teeth, except the upper middle incisors which have already been replaced by the corresponding permanent teeth, and all four of the first permanent molars.[3] This exact dental stage is not well-suited for comparisons, because the permanent incisors follow the first permanent molars at widely varying intervals. In the macaques of the Carnegie Colony the first permanent molars erupt usually during the last four months of the second year, but the first permanent incisors do not follow in most cases until the ages of 2 years and 4 months to 2 years

[3] Exactly the same teeth are present in the skull of a juvenile *H. concolor*, which had by some mistake been labelled in the field as "nursing infant, 2½ months old," and thus misled Kirchner (1895) to the impossible conclusion that in the gibbon the complete milk dentition is present at or very soon after birth and is changed at an extremely early age!

and 10 months. No corresponding data could be found for anthropoid apes of actually known age. The male gorilla "Bamboo" at the Philadelphia Zoological Garden had, when first examined by the author, his complete set of milk teeth. By careful comparisons of weights and measurements with various data in the literature (Schultz, 1930) his age was estimated at 14 months. Exactly two years later the tooth formula of "Bamboo" had not yet changed. At the third examination seven months later, or at the estimated age of 45 months, all four first permanent molars had fully erupted and the upper middle milk incisors appeared to be ready to drop out. "Ngi," the male gorilla at the National Zoological Park, possessed all his milk teeth when first examined at the carefully estimated age of 24 months. Exactly 18 months later, or at the estimated age of 42 months, the author examined "Ngi" for the second time and found that all the first permanent molars were almost completely erupted but there was no sign of an impending change in incisors. At the third examination two years later, when "Ngi" had died at the estimated age of 5½ years, it was found that the permanent middle incisors had erupted in both jaws, though the right upper middle deciduous incisor had not yet been cast off. In the female gorilla "Pensorosa" of the New York Zoological Society the first permanent molars erupted after two years in captivity at the estimated age of 40 to 42 months (Noback, 1930). It seems safe to conclude that the first permanent incisors do not erupt in the gorilla until it is at least four to five years old. In man this happens at the approximate age of seven years or even more. When the author examined the female chimpanzee "Aprilla" and the male orang-utan "Norsuto" at the Philadelphia Zoological Garden, where they had been born, no permanent teeth had appeared as yet, though these apes were respectively 23 and 21 months old, i. e., of the same age as the second young gibbon with his first permanent molars and incisors.

On the basis of these notes it can be concluded that not only the first few deciduous teeth but also the first permanent molars and incisors appear in the gibbon at approximately the same ages as in the macaques and at much earlier ages than in the anthropoid apes and man.

Keith (1931) has recently stated that the "milk teeth of the gibbon begin to appear just after birth and are fully in place by the time it is 6 months old. The permanent dentition begins in the third and is complete in the seventh year." According to the present records this should

be changed to read: The permanent dentition begins during the second half of the second year.

It is to be regretted that there exist at present no data with which to answer the interesting question whether or not the teeth erupt at somewhat later ages in the siamang than in the gibbon.

C. Spinal Column

The number of vertebrae in the different spinal regions varies a great deal in different primates. In regard to these conditions the gibbons and siamangs have already been compared with other primates in a previous paper by the author (1930). With a considerable amount of additional data it has become possible in this study to discuss in particular the differences in the number of vertebrae between the two subgenera of *Hylobates* and between the two genera of the *Hylobatidae*. That such differences do exist is readily seen by the figures in the Tables 8 to 13.

TABLE 8

Percentage Distribution of Variations and Averages of the Number of Thoracic Vertebrae. The Figures in the Tables 8 to 13 are Based Upon the Combined Data Listed in the Tables V and VI of the Previous Paper by the Author (1930) and in Table III of the Present Paper

SPECIES OR SUBGENUS	SPECIMENS	THORACIC VERTEBRAE			AVERAGE
		12	13	14	
Hylobates klossi	5	...	100.0	...	13.0
Hylobates (subgenus)	70	17.1	75.7	7.2	12.9
Symphalangus syndactylus	21	14.3	85.7	...	12.9

TABLE 9

Percentage Distribution of Variations and Averages of the Number of Lumbar Vertebrae

SPECIES OR SUBGENUS	SPECIMENS	LUMBAR VERTEBRAE			AVERAGE
		4	5	6	
Hylobates klossi	5	...	80.0	20.0	5.2
Hylobates (subgenus)	70	7.1	88.6	4.3	5.0
Symphalangus syndactylus	21	47.6	47.6	4.8	4.6

TABLE 10

Percentage Distribution of Variations and Averages of the Number of Thoracolumbar Vertebrae

SPECIES OR SUBGENUS	SPECIMENS	THORACOLUMBAR VERTEBRAE				AVERAGE
		16	17	18	19	
Hylobates klossi	5	...	...	80.0	20.0	18.2
Hylobates (subgenus)	76	...	18.4	76.3	5.3	17.9
Symphalangus syndactylus	23	4.4	47.8	47.8	...	17.4

TABLE 11

Percentage Distribution of Variations and Averages of the Number of Sacral Vertebrae

SPECIES OR SUBGENUS	SPECIMENS	SACRAL VERTEBRAE				AVERAGE
		3	4	5	6	
Hylobates klossi	5	...	20.0	80.0	...	4.8
Hylobates (subgenus)	66	...	57.6	42.4	...	4.4
Symphalangus syndactylus	20	5.0	45.0	45.0	5.0	4.5

TABLE 12

Percentage Distribution of Variations and Averages of the Number of Coccygeal Vertebrae

SPECIES OR SUBGENUS	SPECIMENS	COCCYGEAL VERTEBRAE					AVERAGE
		1	2	3	4	5	
Hylobates klossi	5	...	...	...	40.0	60.0	4.6
Hylobates (subgenus)	56	8.9	39.3	33.9	12.5	5.4	2.7
Symphalangus syndactylus	13	7.7	23.1	46.1	23.1	...	2.8

TABLE 13

Percentage Distribution of Variations and Averages of the Total Number of Vertebrae

SPECIES OR SUBGENUS	SPECIMENS	TOTAL NUMBER OF VERTEBRAE						AVERAGE
		30	31	32	33	34	35	
Hylobates klossi	5	...	...	...	...	40.0	60.0	34.6
Hylobates (subgenus)	56	7.1	33.9	32.1	14.3	8.9	3.7	31.9
Symphalangus syndactylus	13	7.7	30.8	53.8	7.7	...	...	31.6

All five specimens of *Hylobates* (*Brachitanytes*) *klossi* have 13 thoracic vertebrae. In the subgenus *Hylobates* there are still a few cases with 14 of these vertebrae, a number which has not been found in *Symphalangus* and, incidentally, never in orang-utan and in man. The progressive variation of only 12 thoracic vertebrae is more common in the *Hylobatidae* than in the two African anthropoids.

According to the average numbers of lumbar vertebrae (Table 9) the subgenus *Brachitanytes* is the most primitive and the genus *Symphalangus* the most advanced group of the *Hylobatidae*. Only four lumbar vertebrae do not occur in the former, but are found in 48 per cent of the latter group. On the other hand, the retarded variation of six vertebrae is found in one of the 5 *H.* (*B.*) *klossi*, whereas in only one out of 21 siamangs. With an average of only 4.6 lumbar vertebrae the siamang of all *Hylobatidae* approaches most closely the condition in the orang-utan, which possesses on an average 4.0 lumbar vertebrae.

The combined number of thoracic and of lumbar vertebrae (Table 10) varies among *Hylobatidae* between 16 and 19. The group averages extend from 17.4 to 18.2 and fall between the averages of lower catarrhines (macaque = 18.9) and those of the large apes and man (16.0 to 17.0). *Hylobates* (*B.*) *klossi* is again found to be most primitive, no specimen having only 17 thoracolumbar vertebrae. The subgenus *Hylobates* represents an intermediate phase in the evolutionary trend toward reduction of the presacral vertebrae. Nineteen thoracolumbar vertebrae still occur in 5 per cent of the cases, whereas only 17 of these vertebrae are present in 18 per cent of the spinal columns. In the siamang cases with 19 of these vertebrae have disappeared completely and only 17 vertebrae have become very frequent, being found in nearly half of the cases. In one specimen[4] this number has already become reduced even to 16. It is very interesting that a gradual reduction in the number of thoracolumbar vertebrae is clearly recognizable even within the family *Hylobatidae* and that it is the siamang which has, as in so many other features, progressed most (see fig. 8).

In regard to the number of sacral vertebrae the *Hylobatidae* again bridge the gap between the lower catarrhines, with 3 vertebrae, and the

[4] This juvenile siamang was embalmed and partly dissected by the author. With the spine still intact it was found to contain only 12 thoracic and 4 lumbar vertebrae. The unusually low figure of 16 thoracolumbar vertebrae can, therefore, not be suspected as being due to the accidental loss of a vertebra during or after the preparation of the skeleton.

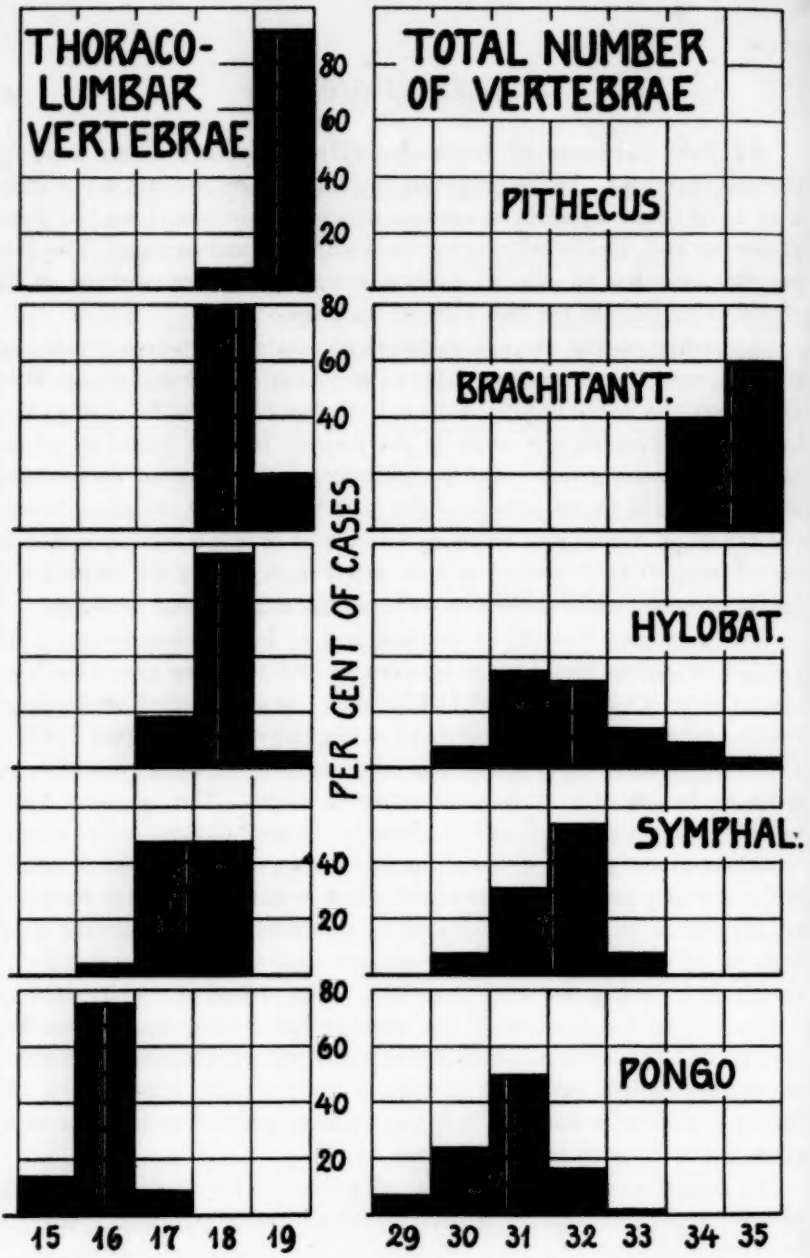

FIG. 8. PERCENTAGE DISTRIBUTION OF VARIATIONS IN THE NUMBER OF THORACOLUMBAR VERTEBRAE (LEFT) AND IN THE TOTAL NUMBER OF VERTEBRAE (RIGHT) IN THE SUBGENERA BRACHITANYTES AND HYLOBATES, IN SYMPHALANGUS (ACCORDING TO TABLES 10 AND 13) AND, FOR GENERAL COMPARISON, IN THE MACAQUE AND IN THE ORANG-UTAN (ACCORDING TO DATA BY SCHULTZ, 1930)

The perpendicular, white, broken lines represent the position of the average number of vertebrae. The variations of the total number of vertebrae in *Pithecus* would, if drawn, lie far to the right of the present diagram.

large apes and man, with 5 and more vertebrae (Table 11). It is significant that the only case with 6 sacral vertebrae among the 90 *Hylobatidae* in Table 11 is a siamang.

All the specimens of *Hylobates* (*B.*) *klossi,* which have been examined, had either 4 or 5 coccygeal vertebrae. In other gibbons and in siamangs 3, 2, and even only 1 coccygeal vertebrae are frequent variations (Table 12). In no other primates, not even the large apes and man, has the caudal portion of the spine become reduced to as few vertebrae as in the gibbons.

The total number of vertebrae (Table 13) varies in *Hylobatidae* between 30 and 35, i. e., within the total range of variations among the anthropoid apes and man. The isolated extremes of the latter range are 29 vertebrae in a few orang-utans and 36 vertebrae in one chimpanzee (Schultz, 1930). None of the five specimens of *Hylobates* (*B.*) *klossi* have less than 34 vertebrae and their average number is three vertebrae higher than the average total number of vertebrae in the siamang. The highest individual variation in siamangs is 33 vertebrae and the average number (31.6) is the second lowest figure for any primate, the minimum (30.8) occurring in the orang-utan (see fig. 8).

In regard to the number of vertebrae the *Hylobatidae* stand between the lower and the highest catarrhines, being nearer to the latter than to the former. The spine of the subgenus *Brachitanytes* is in general more primitive than that of the typical gibbons. The vertebral variations in *Symphalangus* have progressed farther than in any species of *Hylobates.*

D. Sternum

In a paper on the skeleton of higher primates the author (1930) has already shown that the *Hylobatidae* possess a comparatively short and broad sternum which separates these primates sharply from the lower catarrhines. With the additional data in Table IV new averages for the proportions of the sternum have been calculated and listed in Table 14. The combined length of manubrium and corpus averages in the gibbons 57.2 mm. but in the much larger siamangs only 52.2 mm. In the latter the length of the manubrium amounts to nearly 80 per cent of the length of the corpus, whereas in the former to only about 50 per cent. From this can be concluded that the excessive shortening of the sternum in the siamang has affected the *corpus sterni* in particular. The relative breadth of the manubrium is very great in all *Hylobatidae* and

TABLE 14

Average Proportions of the Sternum in Hylobatidae, Based Upon the Combined Data Listed in Table XI of the Previous Paper by the Author (1930) and in Table IV of the Present Paper

SPECIES OR SUBGENUS	SPECIMENS	MANUBRIUM + CORPUS LENGTH (mm.)	MANUBRIUM LENGTH / CORPUS LENGTH	MANUBRIUM BREADTH / MANUBRIUM LENGTH	CORPUS BREADTH / CORPUS LENGTH
Hylobates (subgenus)	20	57.2	52.2	149.2	36.7
Hylobates klossi	2	47.5	60.1	149.6	44.1
Symphalangus syndactylus	6	52.2	77.5	151.0	61.0

is equalled among all catarrhines by the chimpanzee alone. The relative breadth of the corpus differs strikingly in the two genera, being very much smaller in gibbons (37) than in siamangs (61). It is significant that only the orang-utan approaches this relative breadth of the corpus in the siamang. The latter is distinguished by possessing not only the relatively shortest but also the proportionately broadest *corpus sterni* of all primates. In regard to the proportionate length and breadth of the corpus, *Hylobates* (*B.*) *klossi* stands between the gibbons proper and the siamang, though it is much less removed from the former than from the latter. In the subgenus *Hylobates* there are still occasionally found individuals with a very primitive type of *corpus sterni,* which is long and narrow, in which all the different segments remain separate to adult life, and which is still associated with 8 pair of sternal ribs. Such a case in a *H. leucogenys* (N. M. 240495) has been described in the former paper by the writer (1930) and has since been found in a second adult specimen of the same species (N. M. 256436; 5 separate segments for the narrow *corpus sterni*). That this, however, is not a species character is shown by the fact that in two other specimens of *H. leucogenys* (N. M. 256439 and 256088) the sternum is, as usual, short and broad, having in the adult only two segments for the *corpus sterni* and the seventh pair of ribs barely reaching the sternum with extremely slender cartilaginous rods.

E. Pelvis

The pelves of the *Hylobatidae* represent in many respects not only one intermediate phase, but a series of connecting links between the pelves of the catarrhine monkeys on the one hand, and those of the anthropoid apes on the other. As shown, for instance, by figure 9, the

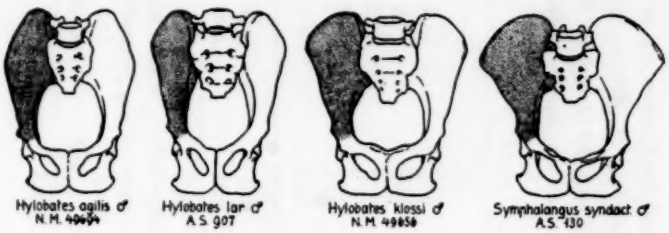

FIG. 9. EXACT FRONT VIEWS OF THE PELVIS IN ADULT HYLOBATIDAE

All reduced to the same total height (drawn with dioptrograph). The right ilia have been dotted to facilitate a comparison between the different forms.

pelvis of the gibbon is still not far removed from the pelvic conditions in monkeys, whereas the pelvis of the siamang resembles already the anthropoid type of pelvis. In regard to the pelvic breadths *Hylobates* (*B.*) *klossi* is intermediate between the true gibbons and the siamangs. These conditions are accurately expressed by the figures in Table 15. The ilium breadth in percentage of the ilium length amounts to as much as 48 in catarrhine monkeys; it averages only 51 in the true gibbons, but 60 in *H. klossi*. In the siamang the ilium has become still broader, the relative breadth averaging 61.2 and amounting in one case to 66.3. The latter value surpasses the corresponding indices in many chimpanzees and in at least one orang-utan. Among *Hylobatidae* the ilium of the siamang is not only unusually broad, but also exceptionally long, whereas the ischium is comparatively short. If the ilium breadth, therefore, is expressed in percentage of the ischium length, one obtains an index which is always much higher in *Symphalangus* than in any *Hylobates*. Among the latter this index varies between 97 and 133, whereas in the former between 144 and 167. By means of this proportion one can readily diagnose the genus to which a particular pelvis belongs. The minimum value of this index (97) among *Hylobatidae* equals approxi-

TABLE 15

Averages of the Ilium Length and of the Proportions of the Pelvis in Hylobatidae and, for Comparison, in Some Lower Catarrhines and Some Anthropoids. The Ranges of Variations are Given in Parentheses for the Gibbons and the Siamangs. Condensed From Table 17 in the Former Paper by the Author (1930) in Which the Measuring Technique is Explained in Detail. To the Series of Siamangs Have Been Added the Data on Another Adult Male Specimen (C. S. No. 58).

PRIMATE	SPECIMENS	ILIUM LENGTH (mm.)	ILIUM LENGTH / ISCHIUM LENGTH	PUBIS LENGTH / ISCHIUM LENGTH	ILIUM BREADTH / ILIUM LENGTH	ILIUM BREADTH / ISCHIUM LENGTH
Pithecus	2	90	204.3	91.1	37.2	76.0
Papio	1	127.0	208.3	83.6	48.0	100.0
Hylobates (subgenus)	23	86.8 (77 - 97)	231.1 (210 - 264)	94.6 (80 - 117)	50.9 (41 - 59)	117.8 (97 - 133)
Hylobates klossi	2	84.5	222.4	94.7	59.7	126.3
Symphalangus syndact.	5	110.8 (104 - 120)	251.1 (242 - 267)	112.3 (104 - 115)	61.2 (58 - 66)	153.6 (144 - 167)
Pongo pygmaeus	2	157.0	189.9	98.8	77.4	147.0
Gorilla gorilla	9	216.0	186.1	95.1	89.7	167.0

TABLE 16

Averages of the Humerus Length and of the Limb Proportions and Ranges of Variations in the Intermembral Index in Adult Hylobatidae. Combined Results of the New Data of this Paper (Table V) and of Those Already Recorded in a Former Paper by the Author (1930)

SPECIES	SPECIMENS	HUMERUS LENGTH (mm.)	BRACHIAL INDEX	CRURAL INDEX	INTERMEMBRAL INDEX	
					Average	Range of Variations
Hylobates lar	9	233.4	112.1	88.1	132.4	(129.2 - 136.9)
Hylobates pileatus	9	228.7	111.0	88.6	124.4	(122.6 - 127.3)
Hylobates cinereus	6	240.2	111.7	88.2	129.0	(122.0 - 132.6)
Hylobates agilis	4	231.5	116.3	88.4	131.3	(129.5 - 134.4)
Hylobates hoolock	3	234.0	109.6	86.8	128.0	(125.0 - 133.0)
Subgenus *Hylobates*	36	230.6	112.4	88.2	128.5	(122.0 - 136.9)
Hylobates klossi	10	201.7	116.5	89.7	126.5	(120.5 - 130.6)
Symphalangus syndact.	16	269.5	111.1	86.1	148.3	(142.0 - 155.0)

mately the maximum value (100) among the lower primates, and the highest value (167) among *Hylobatidae* coincides with the average value of adult gorillas.

It should also be noted that, according to the figures in Table 15, the absolute length of the ilium measures always more than 100 mm. in adult siamangs, whereas always less than 100 mm. in gibbons. By comparison with the former data of the author (1930) it is found that among all primates the siamang possesses the highest averages in regard to two pelvic indices: The ilium length in proportion to the ischium length and the pubis length in proportion to the ischium length. According to this, the pelvis of the siamang is characterized by an exceptionally long ilium and pubis in combination with an unusually short ischium. These are undoubtedly phylogenetically late specializations, having occurred after the separation between the two genera of the *Hylobatidae*.

F. Limb Bones

As shown by Table 16, the humerus of *Hylobates* (*B.*) *klossi* is on an average much shorter than the humeri of the different species in the subgenus *Hylobates*. In individual cases, however, the humerus length of the former rises to 215 mm. (see Table V), whereas among the latter this measurement can be as low as 200 mm. in fully adult specimens (Table XVI, Schultz, 1930). The siamang, as would be expected, possesses by far the longest humerus of all *Hylobatidae*. The shortest humerus of any adult siamang measures 256 mm., whereas the longest humerus among the 46 adult gibbons reaches only 252 mm. The maximum humerus length of siamangs (289 mm.) surpasses the length of this bone in many adult chimpanzees.

The brachial index expresses the length of the radius in percentage of the length of the humerus. According to the averages of this proportion, listed in Table 16, the radius is ten and more per cent longer than the humerus in all adult *Hylobatidae*. This represents a new specialization which has reached a greater extreme in this family than in any other *Simiae*. The orang-utan can approach gibbons in this respect, since the maximum brachial index of this ape amounts to 108.5. The maximum individual value in *Hylobatidae* is 123.9. The relatively longest forearm is found in *H.* (*B.*) *klossi* (average 116.5) and probably in *H. leucogenys* (average of 2 adults in Table 29 = 116.1), the relatively shortest one in *H. hoolock* (average 109.6).

The so-called crural index expresses the length of the tibia in percentage of the length of the femur. The averages of this proportion are remarkably constant among the *Hylobatidae;* the minimum of 86.1 is found in the siamang and the maximum of 89.7 in *H.* (*B.*) *klossi.* The latter, therefore, possesses not only the proportionately longest forearm, but also the relatively longest leg. In lower catarrhines the crural index is on an average higher (91.2) than in the *Hylobatidae,* whereas in the African anthropoids and in man it is lower (78.0 to 86.6).

The sum of the lengths of the humerus and the radius in percentage of the sum of the lengths of the femur and the tibia forms the intermembral index of the skeleton. In the lower primates, with few individual exceptions, the long bones of the upper extremity are shorter than those of the lower one and, consequently, the intermembral index lies below 100. The *Hylobatidae* and anthropoid apes are sharply distinguished from the monkeys by possessing intermembral indices above 100, i. e., by having proportionately long arms. Among the *Simidae* the chimpanzee has the lowest intermembral index with an average of only 108. In the genus *Gorilla* these averages range from 112 to 117. The next higher averages occur in the genus *Hylobates,* namely 124 to 132. These values are followed by the average of 144 for the orang-utan. Finally, the highest intermembral index among all primates exists in the siamang, the average amounting to 148.3 and the individual values ranging to as much as 155. In regard to this important and relatively constant proportion, therefore, the siamang stands nearer to the orang-utan than to the gibbons. The ranges of individual variations do not overlap in the two genera of the *Hylobatidae.* If, in a doubtful case, the intermembral index is obtained as less than 140, the owner belongs to the genus *Hylobates;* if, on the other hand, the index should amount to more than 140, the animal must be a *Symphalangus.*

Within the genus *Hylobates* there exist apparently some species differences in regard to this proportion. The highest average is found in *H. lar* and the lowest one in *H. pileatus.* The ranges of variations of the two species do not overlap. This is of particular interest because Pocock (1927) and Kloss (1929) regard *H. pileatus* as a mere subspecies of *H. lar.* The writer cannot agree with this opinion, because the two types of gibbon represent opposite extremes not only in regard to this comparatively constant intermembral index but also in regard to the relative height of the skull and the relative length of the palate (see

Table 6). The presence of such skeletal differences is certainly at least as significant as the absence of constant differences in hair color.

In regard to the limb proportions *H.* (*Brachitanytes*) *klossi* belongs unquestionably to the genus *Hylobates*. Among all *Hylobatidae, H. klossi* possesses the highest brachial index, the highest crural index, and the second lowest intermembral index. *Symphalangus syndactylus* represents just the opposite extreme in regard to the last two indices and almost the opposite extreme in regard to the brachial index. Of the differences in limb proportions between the various *Hylobatidae* no others are nearly as great as the one between the intermembral indices of the siamang on one side and all the gibbons on the other.

CHAPTER 4. OUTER BODY

G. Hair

In a special paper on the density of hair in primates the author (1931) has demonstrated a striking generic difference between the gibbons and the siamangs, according to which the former are much more hairy than the latter. Table 17 serves to show this entirely unexpected difference which is not apparent, unless the numbers of hairs have actually been counted on sample areas of skin of well preserved specimens. After his first investigation of hair density the author examined the largest of the preserved specimens of *Hylobates* (*Brachitanytes*) *klossi*. The surprising result shows the density of hair in this animal to be very much more scanty than in the typical gibbons, but to agree closely with the density of the hair of the siamang. That the approximate total numbers of hairs are higher in the latter than in the former is due to the difference in surface area between the large and the small animal.

The subgenus *Hylobates* is characterized by a very great density of hair which, as was shown in the previous study, equals approximately the average density in platyrrhines and surpasses the density of many catarrhine monkeys. In the subgenus *Brachitanytes* and in the genus *Symphalangus* the density of hair is more scanty than in most lower catarrhines, but it is still somewhat greater than in anthropoid apes in which this density has become tremendously reduced.

TABLE 17

*The Density and Approximate Total Number of Hairs in Hylobatidae and, for Comparison, in Anthropoid Apes (Averages). * = Wild-shot Specimen. Condensed from Another Paper by the Author (1931), Except for the New Data for Hylobates klossi*

COLL. NO.	SPECIES	AGE	HAIRS PER SQ. CM.			TOTAL NUMBER OF HAIRS (DIVIDED BY 1000)		
			Scalp	Back	Chest	Scalp	Back	Chest
J. H. 125	*Hylobates pileatus* *	adult	2,096	....	...	249.6	....	....
J. H. 261	*Hylobates lar*	adult	2,189	1,834	359	237.0	898.0	175.6
J. H. 36	*Hylobates agilis*	juven.	1,633	2,030	578	172.5	601.5	171.2
J. H. 205	*Hylobates cinereus*	juven.	2,047	1,226	635	206.0	371.0	192.0
J. H. 204	*Hylobates cinereus*	juven.	2,244	1,630	403	254.6	455.0	112.4
J. H. 182	*Hylobates cinereus*	juven.	2,017	1,896	594	205.8	609.7	190.6
J. H. 152	*Hylobates cinereus* *	adult	2,093	1,858	888	210.5	905.0	432.0
J. H. 189	*Hylobates cinereus* *	adult	2,043	1,174	355	254.0	760.1	229.7
N. M. 121682	*Hylobates klossi* *	juven.	663	462	277	51.1	61.7	37.0
N. M. 255980	*Symphalangus syndact.*	juven.	718	429	251	87.5	206.0	120.6
Averages of Anthropoid apes		.....	307	276	90	142.9	380.6	110.8

In the true gibbons[5] the region of the throat bears, as a rule, as dense a coat of hair as the chest. In *H. klossi,* on the other hand, the hair in this region is decidedly less dense than on the surrounding skin, at least in the few specimens examined by the author. In the siamang, finally, this region bears only a few scattered hairs and has become specialized into a large throat pouch (see figure *A,* plate 1). This throat pouch does not develop until the early juvenile stages of growth. It is present in both sexes, though very much larger in full-grown males than in any females. The presence of this pouch alone would justify the generic separation of the siamang from all other *Hylobatidae.*

It is frequently stated in the literature that all hair of the siamang is black. The adult specimens examined by the author, however, have hairs of a yellowish-white color on the upper and the lower lip and on the chin (plate 1, *A*). In at least two of the largest siamangs the throat pouch also bears hair of this light color.

To these notes on hair may be added some remarks on the direction of the hair. Since the writer's observations agree essentially with what Chasen and Kloss (1927) have already stated, their conclusions will be quoted in the following:

> In most of the typical gibbons we have examined the hair on the outer side of the forearm points toward the wrist: in the siamang it points to the elbow. Among the Mentawi animals (*H. klossi*) the two Sipora specimens have the hair pointing towards the elbow as in our siamangs, but in the Siberut series (also *H. klossi*!) the hair on the distal half of the outer forearm points toward the wrist. A mounted topotype from the Pagi Islands has the hair of one forearm pointing towards the wrist and of the other towards the elbow.

As in regard to so many other characters, it is again found that the siamang differs from the typical gibbons and that the subgenus *Brachitanytes* occupies with various features an intermediate position.

H. Digital Webbing

It is frequently supposed that the cutaneous webbing between the second and third toes is a peculiarity restricted to *Symphalangus syndactylus,* as its name would imply. That this, however, is not the case, is

[5] In a few old male gibbons it was found that a small zone of skin above the suprasternal notch bears strikingly scanty and short hair which gradually becomes denser and longer as it approaches the sides of the neck, the chin and the chest. This condition is clearly present, e. g., in a large adult male *Hylobates leucogenys* (No. 256439, N. M.).

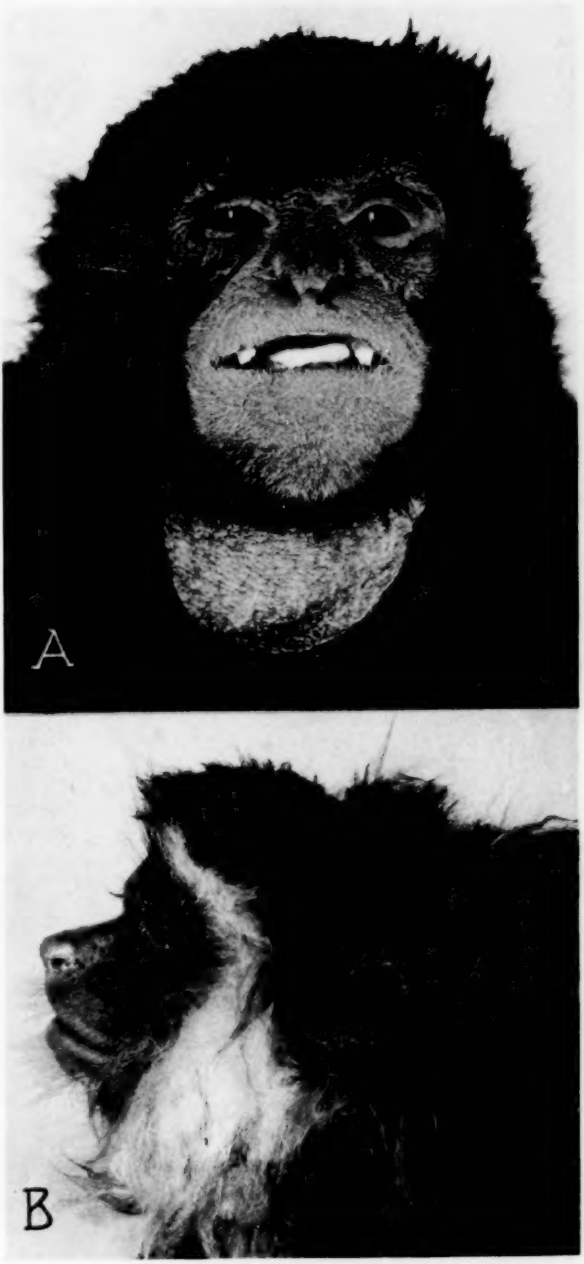

PLATE 1. *A* = FRONT VIEW OF HEAD OF SYMPHALANGUS SYNDACTYLUS, ♂, JUVENILE (N. M. No. 255980) SHOWING MODERATELY DISTENDED THROAT POUCH. B = SIDE VIEW OF HEAD OF HYLOBATES CINEREUS, ♀, JUVENILE (J. H. No. 205) WITH UNUSUALLY PROMINENT NOSE.

TABLE 18

Cutaneous Webbing Between the Toes II and III in Hylobatidae According to the Author's Observations and the Data by Schwalbe (1911) and by Straus (1926). Webbing "to the Middle of Basal Phalanx" is Extremely Short Because the Sole of the Foot Reaches Practically that Far

SPECIES OR SUBGENUS	SPECIMENS	TO MIDDLE OF BASAL PHALANX	TO END OF BASAL PHALANX	TO MIDDLE OF MIDDLE PHALANX	TO END OF MIDDLE PHALANX
PRESERVED SPECIMENS (Schultz)					
Hylobates concolor	12	8	3	1	0
Hylobates lar	7	6	1	0	0
Hylobates cinereus	5	5	0	0	0
Hylobates pileatus	17	15	1	1	0
Hylobates agilis	3	3	0	0	0
Hylobates leucogenys	5	5	0	0	0
Hylobates klossi	4	0	1	3	0
Symphalangus syndact.	14	0	1	7	6
PRESERVED FETUSES (Schwalbe)					
Subgenus *Hylobates*	19	13	6	0	0
Symphalangus syndact.	4	0	0	2	2
SKINS (Straus)					
Subgenus *Hylobates*	40	36	2	2	0
Symphalangus syndact.	22	9	9	4	0
PERCENTAGE FREQUENCIES IN THE COMBINED SERIES					
Subgenus *Hylobates*	108	84	12	4	0
Subgenus *Brachitanytes*	4	0	25	75	0
Genus *Symphalangus*	40	22	25	33	20

evident from the data collected in Table 18. In the siamang this webbing can extend farther than in any of the gibbons, namely to the second interphalangeal joint, but this happens in only 20 per cent of the cases. In 4 per cent of the typical gibbons toes II and III are united as far as the middle of the middle phalanges and in 12 per cent as far as the distal end of the basal phalanges. In a number of siamangs, on the other hand, this webbing is no more developed than in many gibbons;

indeed, in 22 per cent of the former there exists practically no webbing, whereas in 16 per cent of the latter the second and third toes are clearly webbed. Digital webbing, therefore, cannot be regarded as a character distinguishing the genus *Symphalangus;* it occurs also in the gibbons and in a variety of other primates. For instance, in at least two of the many chimpanzees examined by the author toes II and III are united by a cutaneous web as far as the distal interphalangeal joint. In *Hylobates* (*Brachitanytes*) *klossi* extensive webbing seems to be more common than in the subgenus *Hylobates,* but it has not been seen to reach quite as far as in some siamangs. This agrees with the finding of Kloss (1929) who states that in *H. klossi* "the digital webs are less developed than in the Siamang but more so than in many other gibbons."

I. Length of Digits

In all lower catarrhines the second finger is shorter than the fourth finger and the second toe is shorter than the fourth toe. The same relation exists in all orang-utans and in the great majority of chimpanzees and gorillas. In a few of the African apes, however, the second digit is as long as the fourth on the hand as well as on the foot, and in 3 out of

TABLE 19

Relations in Length Between the Digits II and IV. Observed on the Outer Hands and Feet of Preserved Specimens. II<IV = Digit II Shorter Than Digit IV; II > IV = Digit II Longer than Digit IV

SPECIES	SPECIMENS	FINGER			TOE		
		II < IV	II = IV	II > IV	II < IV	II = IV	II > IV
Hylobates concolor	12	4	6	2	5	3	4
Hylobates lar	7	1	1	5	2	3	2
Hylobates cinereus	5	2	0	3	1	3	1
Hylobates pileatus	17	5	5	7	3	7	7
Hylobates agilis	3	1	2	0	2	0	1
Hylobates leucogenys	5	1	2	2	2	3	0
Subgenus *Hylobates*	49	14	16	19	15	19	15
Hylobates klossi	4	1	3	0	1	2	1
Symphalangus syndact.	14	1	3	10	3	7	4

48 preserved chimpanzees the second toe surpasses the fourth in length. In man the second toe always projects beyond the fourth and the index finger is very frequently longer than the ring finger. Man, therefore, would differ in these respects from all the other primates, were it not for the conditions in the *Hylobatidae*. In the latter family, as shown by Table 19, the second digit reaches either as far as the fourth or even farther in the great majority of cases. This is particularly common in the siamangs, among which only one out of 14 specimens has the second finger shorter than the fourth. Among gibbons this relation still occurs in 14 out of 49 specimens.

(To be concluded)

TRENDS IN THE FERTILITY OF SOCIAL CLASSES FROM 1900 TO 1910[1]

BY CLYDE V. KISER

This paper concerns itself with changes in the fertility of specific social classes during the first decade of the century. Trends of the general birthrate in this country have frequently been studied but in only a few instances have factual investigations been made of the differential changes with reference to social classes. Baber and Ross [2] and Sydenstricker [3] made such studies on the basis of small samples. Notestein and Sallume [4] have recently compared the *completed* fertility of married women at different age levels for whom data were extracted from the 1910 Census returns. The present study is based upon data taken from the 1900 and 1910 Census data for married women of childbearing age.

In the censuses of 1890, 1900, and 1910, the enumerators asked each married woman the number of children she had borne. The returns were never tabulated by the Bureau of the Census, however, and except by Hill [5] remained practically untouched for a long time.

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[1] This is the eleventh study of differential fertility carried out under the auspices of the Division of Research, Milbank Memorial Fund. It is the first based upon 1900 Census data. With the exception of (f), the articles listed in the Appendix are based exclusively upon the 1910 Census material. The writer wishes to express his indebtedness to Dr. Frank W. Notestein for his invaluable assistance in the preparation of this paper.

[2] Baber, R. E., and Ross, E. A.: Changes in the Size of American Families in One Generation. University of Wisconsin Studies in the Social Sciences and History, No. 10, *Madison,* 1924.

[3] See (f), Appendix.

[4] See (g) and (i), Appendix.

[5] Dr. Joseph A. Hill tabulated samples from the 1900 Census returns as the basis for a study, *Fecundity of Immigrant Women.* While this study indicates in a broad manner class differences of fertility, it was concerned with showing differences in fertility according to nativity and country of birth rather than social class *per se.*

Hill, Joseph A.: Fecundity of Immigrant Women. Reports of the Immigration Commission, *Washington,* Government Printing Office, 1911, xxviii, pp. 731-826.

Inasmuch as the occupations of husbands of women who had borne specified numbers of children were recorded, these data are well adapted to the study of fertility of social classes.[6] For this reason, the Milbank Memorial Fund undertook to study the fertility of a sample of approximately 100,000 native born white women living in thirty-three cities of 100,000-500,000 population and in rural areas north of the Mason and Dixon Line.

Through the coöperation of Professor W. F. Ogburn, Director of Research of the President's Research Committee on Social Trends it was possible to secure analogous material from the 1900 Census, and thereby to study the trends in the fertility of various social classes from 1900 to 1910.

THE COMPARABILITY OF THE TWO SAMPLES

Since the 1900 data were confined to women living in the East North Central States, the comparison of rates of 1900 with those of 1910 was limited to this area. The data from the two censuses are similar in essential respects such as nativity, race, age, marital status,[7] type of community, and division into social classes. Only native white married women under 45 years of age living at the time of enumeration with husbands of like nativity are considered in this study. Similar divisions of the data with respect to urban and rural residence were made. It will

[6] For some years the Bureau of the Census has published annually the average number of children ever born to mothers bearing children that year, by age of mother and occupation of father in the registration area of continental United States. These data, however, are not given separately by race, nativity, or rural and urban residence, and cannot in the nature of the case take account of childless women. The value of such data for studies of differential fertility according to social class is therefore considerably diminished.

[7] The 1910 data were taken only for native white married women from families in which neither the husband nor wife had been married more than once. Information concerning the number of times married could be obtained directly from the 1910 Census schedules. In case of 1900 data, however, the information was lacking and had to be secured in an indirect manner. If the duration of marriage exceeded the age of the oldest child, it was assumed that neither the husband nor the wife had been married more than once. The inadequacy of the method consisted in the fact that it did not eliminate those cases in which the earlier marriage was childless and those in which all of the children either had died or had left home prior to the 1900 enumeration. It seems reasonable to believe, however, that the number of cases thus erroneously included in the sample is small and that they comprise a group whose earlier marriages were least likely to modify the fertility of existing unions.

be noted from Table 1 that cities represented in the 1910 urban sample are generally larger than those of the 1900 sample. The cities included in both samples, Columbus, Dayton and Grand Rapids, had normal increases of population during the decade. Peoria and Evansville, relatively small cities in 1900 were included only in the sample drawn from the census of that date. Cincinnati, Toledo, Indianapolis, Detroit, and Milwaukee, relatively large cities, were included only in the 1910 sample. It is believed, however, that such differences would not vitiate a temporal comparison of urban fertility rates.[8] Although the cities considered in the two enumerations roughly range in population from 50,000 to 450,000, all of them could be regarded as moderately urban communities. None could be considered as villages or metropolises in 1900 or 1910. The rural samples from the two enumerations were drawn in large part from identical counties. Variations are indicated in Table 2.

Precisely the same system as was used in preceding studies of the 1910 data was followed in building up social classes from specific occupations.[9] As pointed out in the previous studies, the reported husbands'

[8] In order to ascertain whether or not fertility is associated with differences of population within a group of moderately urban communities, birth rates (births per 100 wives, standardized for age) for two social classes were computed for each city represented in the 1910 sample. The following results were found:

Cities of More than 200,000 in 1910	Births per 100 Wives		Cities under 200,000 in 1910	Births per 100 Wives	
	Business Class	Skilled Workers		Business Class	Skilled Workers
Detroit	130	167	Columbus	147	205
Milwaukee ...	142	151	Toledo	130	182
Cincinnati	137	193	Dayton	156	181
Indianapolis ..	150	208	Grand Rapids ...	144	181

From Table 1, it will be noted that the four largest cities had more than 200,000 population and the four smallest fewer than that number. The range in the rates for either social class however, is practically the same in the two groups of cities represented. Without doubt the influence of urbanization upon the birth rate may be seen when communities differing widely in size are compared. The above data, however, indicate that among *moderately urban* communities size of population is not of first consequence. It seems, therefore, that the comparison of 1900 and 1910 urban fertility rates should not be invalidated by differences in the sizes of the cities represented in the two samples.

[9] For a full discussion of the division of wives into social classes, see Sydenstricker, Edgar, and Notestein, F. W.: Differential Fertility According to Social Class.

TABLE 1

Total Population of Cities and Number of Native White Married Women of Native Parentage for Whom Fertility Data were Extracted from the 1900 and 1910 Census Schedules

CITY	1900		1910	
	Total Population	Number of Women Considered	Total Population	Number of Women Considered
Columbus	125,560	5,292	181,511	2,500
Cincinnati	.....	....	363,591	1,305
Dayton	85,333	3,842	116,577	2,010
Toledo	.....	....	168,497	1,457
Indianapolis	.....	....	233,650	4,432
Evansville	59,007	1,383	.....	....
Grand Rapids	87,565	1,631	112,571	708
Detroit	.....	....	465,766	1,256
Peoria	56,100	1,605	.....	....
Milwaukee	.....	....	373,857	442
Unknown	.....	47 *	.....	....
Total	.....	13,800	.....	14,110

* The women represented here resided in one of the localities listed above, but the specific residence is unknown due to errors or omissions in coding.

TABLE 2

Geographic Distribution of Rural Native White Married Women of Native Parentage for Whom Fertility Data Were Extracted From the 1900 and 1910 Census Schedules *

STATE	1900	1910
Ohio	2,931	6,871
Indiana	934	2,810
Michigan	1,851	1,272
Illinois	1,273	....
Wisconsin	....	294
Unknown	1 †	....
Total	6,990	11,247

* The 1900 rural sample was drawn from the following counties in the several states: Ohio: Fayette, Highland, Madison, Medina, and Wood; Indiana: Orange, Randolph, and Steuben; Michigan: Allegan, Gratiot, and Lenawee; Illinois: Bureau, Champaign, and Jersey. Illinois was not included in the 1910 rural sample but data were drawn from Wisconsin counties: Grant, Jefferson, Sheboygan, and Trempealeau. All of the counties in the three remaining states of the 1900 rural sample were included in the 1910 sample. Tuscarawas and Wayne counties, Ohio; White County, Indiana; and Huron County, Michigan were also represented in the 1910 rural sample.

† Due to error in coding.

occupations do not furnish entirely satisfactory criteria for the assignment of wives into social classes. Aside from the inaccuracies of reporting occupations and aside from the wide range of character and training of individuals represented in specific occupations, it is well

TABLE 3

Distribution of Married Women of Native White Parentage for Whom Fertility Data Were Extracted From the 1900 and 1910 Census Schedules According to Occupational Group and Social Class of Husbands

SOCIAL CLASS AND OCCUPATIONAL GROUP	NUMBER OF WOMEN	
	1900	1910
Total	20,790	25,357
Total from Cities	13,800	14,110
Professional	873	2,060(1)
Lawyers, judges, and justices	220	487
Physicians and surgeons (2)	215	495
Technical engineers (3)	62	233
Teachers in colleges and schools (4)	95	189
Clergymen	88	171
Dentists	57	160
Accountants and auditors	19	79
Editors and reporters	44	62
Architects	27	61
Other professional persons (5)	46	123
Business	4,609	5,080
Salesmen and clerks in stores	646	811
Retail dealers	711	604
Commercial travelers	489	473
Real estate agents and officials	80	121
Bookkeepers and cashiers	359	301
Builders and building contractors	92	204
Manufacturers and officials of manufacturing	242	263
Managers and superintendents of manufacturing	91	172
Insurance agents and officials of insurance companies	196	187
Brokers, commission men and promoters	73	76
Wholesale dealers, importers and exporters	59	73
Agents, canvassers, and collectors	161	188
Draftsmen	24	159
Conductors (steam railroad)	148	138
Bankers and bank officials	38	39
Other owners, proprietors, and managers (6)	277	226
Other clerical and kindred workers (7)	923	1,045

TABLE 3—*Continued*

SOCIAL CLASS AND OCCUPATIONAL GROUP	NUMBER OF WOMEN	
	1900	1910
Skilled Laborers	6,136	5,696
Carpenters	625	493
Brick and stone masons	96	58
Other skilled laborers in building trades	48	57
Machinists, millwrights, and tool makers	551	706
Foremen and overseers	184	197
Plumbers and gas and steam fitters	85	123
Blacksmiths, forgemen, and hammermen	205	87
Semi-skilled operatives (n.o.s) (8) in mfg. industry	1,063	820
Painters, glaziers, varnishers, enamelers, etc.	402	303
Locomotive engineers and firemen (steam railroad)	217	280
Engineers (stationary), cranemen, hoistmen, etc.	220	173
Brakemen, switchmen, flagmen, and yardmen	259	247
Electricians	68	153
Conductors and motormen (street railroad)	323	368
Compositors, linotypers, typesetters, etc. (9)	185	176
Barbers and hair dressers	167	158
Other skilled workers (10)	1,086	925
Other semi-skilled workers (11)	352	372
Unskilled Laborers	2,182	1,274
Draymen, teamsters, expressmen, and carriage and hack drivers	444	230
Laborers (building, general, and not specified)	1,048	241
Laborers (n.o.s.) (8) in manufacturing industries	179	298
Laborers engaged in transportation	105	67
Other laborers (12)	406	438
Total from Rural Districts	6,990	11,247
Farm owners	3,065	4,649
Farm renters	2,787	4,911
Farm laborers	1,138	1,687

(1) The 1910 professional sample was obtained from three times as many schedule pages as those for the other urban classes. In computation of birth rates for the total urban class of 1910, the professional sample is therefore given one-third its actual weight.

(2) Includes: Veterinary surgeons and osteopaths.

(3) Includes: Civil engineers and surveyors, electrical, mechanical, and mining engineers.

(4) Includes: College presidents and teachers of dancing.

(5) Includes: Artists, chemists, assayers and metallurgists, designers, and other professional persons.

known that "social class" is a nebulous concept. Young individuals who are unskilled laborers at the time of one enumeration may rise into the ranks of skilled, business, or even professional classes in later enumerations. It is believed, however, that within each class there are sufficient similarities with reference to education, income, and general standards of living to warrant classification, and that regardless of "overlapping" the classes are more or less self-contained entities. The occupations included in the different social classes of the 1900 and 1910 samples and the number of cases in each occupation are given in Table 3. While evidence might be adduced to indicate that a few occupations were not allocated correctly, the numbers included in such doubtful cases are relatively small and unimportant. The classification of the rural wives into the three groups, farm owners, farm renters, and farm laborers, was much simpler inasmuch as each of these classes contained no subdivisions and the basic data could be tabulated directly from the census schedules.

(6) Includes: Managers and operators engaged in transportation and extraction of minerals, etc.

(7) Includes: Baggagemen and freight agents; ticket, station, and express agents; express messengers and railway mail clerks; mail carriers; telegraph and telephone operators; floorwalkers, decorators, milliners, inspectors, gaugers and samplers; musicians and teachers of music; semi-professional pursuits; actors and showmen; housekeepers and stewards; auctioneers; trained nurses; abstractors; healers; officials of lodges and societies; and stenographers and typists.

(8) Not otherwise specified.

(9) Electrotypers, stereotypers, lithographers, pressmen and plate printers are also included.

(10) Includes: Bakers; boilermakers; engravers; jewelers, watchmakers, goldsmiths, and silversmiths; mechanics; moulders, founders, and casters (of metal); pattern and model makers; tailors; tinsmiths and coppersmiths; other skilled workers in non-precious metal; proprietors and managers of garages, transfer companies, and livery stables; inspectors (transportation); firemen (fire department); policemen; photographers; detectives, sheriffs, and keepers of institutions; and cooks.

(11) Includes: Mine, quarry, and oil and gas well operatives; filers, grinders, buffers, and polishers (metal); chauffeurs; telegraph and telephone linemen; other semi-skilled operatives engaged in transportation industries; boarding and lodging house keepers; launderers, and laundry operatives; waiters and bartenders.

(12) Includes: Firemen (except locomotive and fire department); laborers in coal and lumber yards, warehouses and stores; laborers in public service; bootblacks, cleaners, janitors and sextons, elevator tenders; other laborers in domestic and personal service; guards, watchmen, doorkeepers, and guides (public service).

The percentage age distributions of the wives under 45 years of age are graphically illustrated in Figure 1. As a group, the wives of men of professional status were older than those of the other urban classes. In the rural classes, the wives of the farm owners constituted the oldest

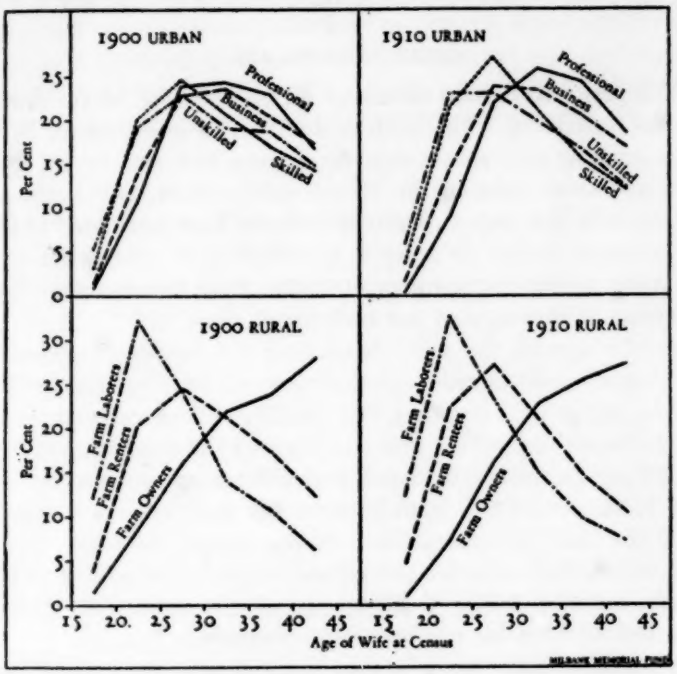

FIG. 1. DISTRIBUTION ACCORDING TO AGE OF WIVES IN EACH SOCIAL CLASS IN 1900 AND 1910

TABLE 4

Median Ages of Wives of Men of Different Social Classes

SOCIAL CLASS	MEDIAN AGE	
	1900	1910
Professional	32.9	33.6
Business	32.5	32.3
Skilled Workers	30.5	29.6
Unskilled Laborers	30.7	29.7
Farm Owners	35.4	35.6
Farm Renters	30.3	29.2
Farm Laborers	26.1	26.0

group, the farm renters were intermediate and the wives of farm laborers were much younger than those of any other social class, rural or urban. The median ages presented in Table 4 indicate that whereas there are distinct differences between the average ages of certain social classes, little change was manifested from 1900 to 1910 in any group.

CORRECTION FOR AGE

In this paper 1900-1910 trends of the net fertility of various social classes are considered. The birth rate of a class is influenced by many variables such as age, age at marriage, fecundity, and by an intricate complex of factors inherent in the interests, culture, and mode of life characteristic of the group. Various students have attempted to control certain of these factors in order to ascertain their relative importance. In this study, however, the composite rather than the separate effects of these factors is investigated for each social class.

Since the age of the wife determines the length of exposure to biological and environmental conditioners of fertility, however, it is only when age is held constant that fertility differences emerge which can be attributed to inherent characteristics of the specific social classes. Unless the age factor is considered, true differences between the fertility rates of farm owners and farm laborers, for instance, are concealed by virtue of the older age composition of the former class.

Age at marriage also determines the length of exposure to risk of childbirth, but this factor itself is one of the social conditioners of fertility and as such has not been held constant.

The fertility index used in this study is the number of children ever born per 100 wives. Such a rate may be regarded as *cumulative* in the sense that it is an index of the total past fertility of the women considered as distinguished from a current rate based upon the annual number of births.

The differences in the age composition of the various social classes are met by two statistical methods. The first is that of computing age-specific rates which afford valid comparisons of the fertility of women in different social classes but in the same age groups. The other device is that of applying a common age standard to the age-specific rates and deriving thereby a total rate standardized for age for each social class.[10]

[10] The standard used is the age distribution of the total sample secured from the 1910 Census schedules. It is not, therefore, limited to the East North Central States. See (a), Appendix.

The total rates standardized for age are indices of the fertility which one might expect if the wives of the different social classes had the same age distribution.

RURAL AND URBAN RATES

The age specific rates, children born per 100 wives are presented in Table 5 for the total rural and urban classes of 1900 and 1910. The corresponding rates standardized for age are given in Table 8. Two facts stand out when these data are expressed graphically, Figure 2. In

TABLE 5

Children Born per 100 Wives and Basic Data by Age of Wife at the 1900 and 1910 Censuses for Urban and Rural Areas

AGE OF WIFE	Urban 1900	Urban 1910	Rural 1900	Rural 1910
CHILDREN BORN PER 100 WIVES				
Total under 45..	191	168	271	258
15-19	47	54	64	54
20-24	91	91	125	117
25-29	142	134	201	201
30-34	201	178	297	289
35-39	258	222	365	345
40-44	308	266	406	400
CHILDREN BORN				
Total under 45..	26,343	21,427 *	18,921	29,042
15-19	179	189	184	255
20-24	2,176	2,091	1,499	2,330
25-29	4,659	4,279	2,919	4,971
30-34	6,037	5,007	4,253	6,778
35-39	6,700	5,074	4,884	7,122
40-44	6,592	4,787	5,182	7,586
WIVES				
Total under 45..	13,800	12,737 *	6,990	11,247
15-19	381	353	288	471
20-24	2,403	2,287	1,198	1,991
25-29	3,284	3,203	1,455	2,477
30-34	2,997	2,808	1,432	2,349
35-39	2,595	2,287	1,339	2,062
40-44	2,140	1,799	1,278	1,897

* *Cf.* Footnote 1, Table 3.

the first place, as early as 1900 the rural fertility rates were much higher than were those for the urban group. This was true for women of all ages but the differences were small among the younger wives. The accentuation of these differences with increasing age suggests the greater prevalence of large families in rural homes than in the homes of the city.

In the second place, whereas the urban rate declined considerably during the 1900-1910 interval, the change in the rural rate was less

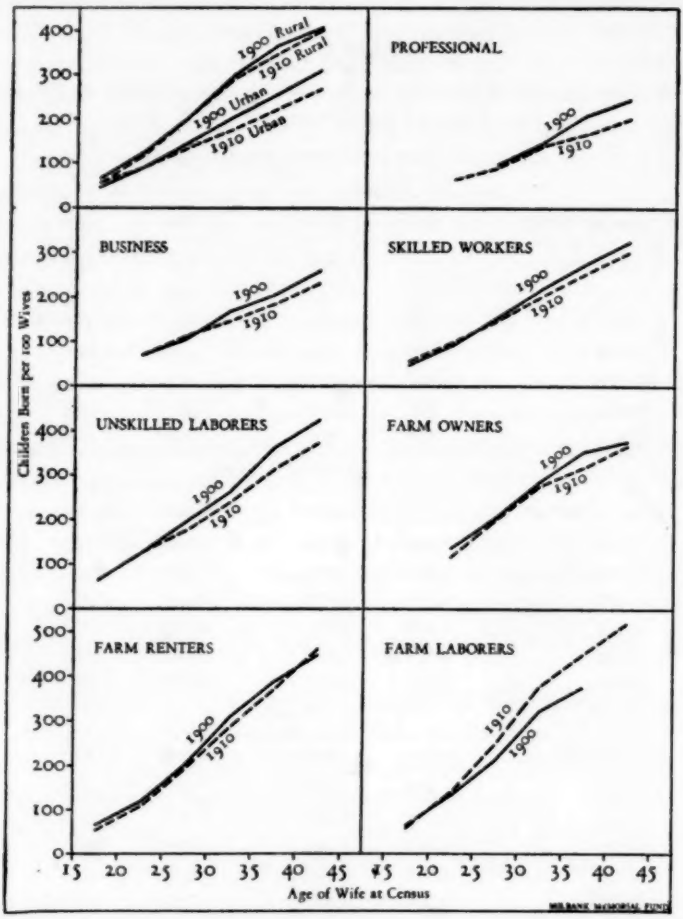

FIG. 2. COMPARISON OF THE FERTILITY OF WIVES IN 1900 WITH THAT IN 1910, BY URBAN AND RURAL AREAS AND BY SOCIAL CLASSES

important. The rural-urban difference of fertility rates was therefore accentuated during the decade. The total rural rate standardized for age was 270 in 1900 and 262 in 1910, and that for the total urban centers fell from 193 in 1900 to 173 in 1910. The decline in the rural rate was only 3 per cent during the decennium, while the urban rate decreased by approximately 10 per cent. In 1900 the rural rate was 40 per cent higher than the urban rate; in 1910 it was about 51 per cent higher.

The fall in the urban birth rate during the ten years under consideration was due in large part to the declining fertility of women in the higher orders of ages. There was no decline whatsoever in the rate for women under 20 years of age. The rates for women 20-24 years of age were also practically the same in 1900 and 1910 and those for women 25-29 were little different. It would seem that the decadal decrease in fertility came about by virtue of the dwindling proportion of large families.[11]

RATES BY SOCIAL CLASS

In 1900 the birth rates of the urban group were much more clearly differentiated by social class than those of the rural population. The

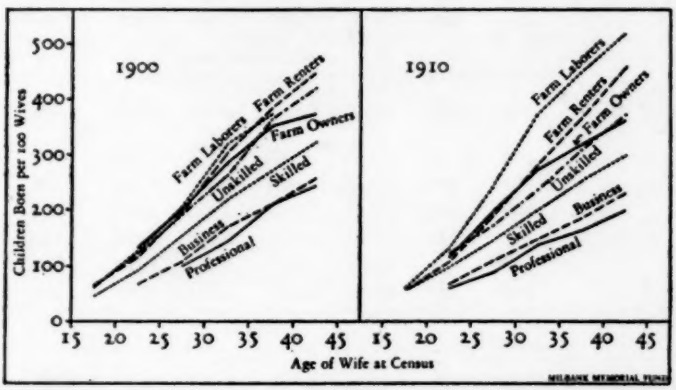

FIG. 3. COMPARISON OF THE FERTILITY OF WIVES ACCORDING TO SOCIAL CLASS, 1900 AND 1910

[11] This is also indicated by a recent investigation in which the trends in the size of families from 1890 to 1910 were studied by comparing the families of women 40 to 44 years of age in 1910 with those of women 60 to 64. Large families became less frequent in each social class. During the interval there were increasing proportions of women who bore less than two children and decreasing proportions who bore five or more children. See (e), Appendix.

four urban classes fell into three fertility groups since there was little difference in the rates of professional and business classes, Table 6 and Figure 3. The two latter, the white collar classes, comprised the lowest fertility group, the skilled workers stood intermediate in position, and the unskilled laborers were the most fertile urban dwellers.

TABLE 6

Children Born per 100 Wives and Basic Data by Age of Wife at the 1900 and 1910 Censuses for Each Urban Class

AGE OF WIFE	Professional		Business		Skilled Workers		Unskilled Laborers	
	1900	1910	1900	1910	1900	1910	1900	1910
	CHILDREN BORN PER 100 WIVES							
Total under 45....	155	138	163	148	196	179	251	217
15-19	*	*	*	*	45	55	62	*
20-24	*	62	67	68	94	99	125	124
25-29	98	90	109	112	154	147	192	175
30-34	146	138	170	149	218	200	262	239
35-39	210	167	209	186	271	254	363	311
40-44	245	200	258	231	323	299	422	373
	CHILDREN BORN							
Total under 45....	1,354	2,852	7,501	7,540	12,004	10,178	5,484	5,096
15-19	4	1	18	30	85	110	72	49
20-24	51	114	433	490	1,167	1,199	525	364
25-29	206	405	1,147	1,358	2,344	2,274	962	512
30-34	311	735	1,856	1,762	2,777	2,401	1,093	599
35-39	422	840	1,978	1,930	2,819	2,207	1,481	657
40-44	360	757	2,069	1,970	2,812	1,987	1,351	578
	WIVES							
Total under 45....	873	2,060	4,609	5,080	6,136	5,696	2,182	1,274
15-19	6	8	68	77	191	202	116	71
20-24	96	185	649	720	1,239	1,212	419	293
25-29	210	452	1,055	1,210	1,518	1,549	501	293
30-34	213	534	1,089	1,180	1,277	1,199	418	251
35-39	201	502	945	1,040	1,041	869	408	211
40-44	147	379	803	853	870	665	320	155

* Rates based on fewer than 100 cases are not shown.

In the rural population, Table 7 and Figure 3, the rates for the farm owners, farm renters, and farm laborers were not so divergent as are those for urban classes. The small differences and the fact that the curves cross each other attest the generally undifferentiated nature of the rural rates in 1900. The rates for the farm owners, 35 years of age and over, however, are probably significantly lower than those for the farm renters and farm laborers of the same age groups, and the total

TABLE 7

Children Born per 100 Wives and Basic Data by Age of Wife at the 1900 and 1910 Censuses for Each Rural Class

AGE OF WIFE	Farm Owners		Farm Renters		Farm Laborers	
	1900	1910	1900	1910	1900	1910
	CHILDREN BORN PER 100 WIVES					
Total under 45	297	285	262	238	221	243
15-19	*	*	65	54	61	57
20-24	133	117	118	109	130	134
25-29	201	198	198	190	207	241
30-34	285	275	304	281	319	375
35-39	351	318	384	368	372	449
40-44	375	365	447	459	*	519
	CHILDREN BORN					
Total under 45	9,094	13,240	7,313	11,704	2,514	4,098
15-19	29	15	70	121	85	119
20-24	347	391	672	1,197	480	742
25-29	987	1,483	1,360	2,542	572	946
30-34	1,932	2,931	1,810	2,901	511	946
35-39	2,579	3,773	1,855	2,622	450	727
40-44	3,220	4,647	1,546	2,321	416	618
	WIVES					
Total under 45	3,065	4,649	2,787	4,911	1,138	1,687
15-19	41	39	108	224	139	208
20-24	261	335	568	1,102	369	554
25-29	492	750	687	1,335	276	392
30-34	677	1,066	595	1,031	160	252
35-39	735	1,187	483	713	121	162
40-44	859	1,272	346	506	73	119

* Rates based on fewer than 100 cases are not shown.

rates standardized for age seem to indicate that a differentiation of the three rural classes was at least beginning to be manifested by 1900.

It is interesting to note that although the fertility rates for the total rural group were much higher than those for the total urban in 1900, the urban unskilled laborers were characterized by fertility rates much nearer to those of the rural classes than to those of the urban women.

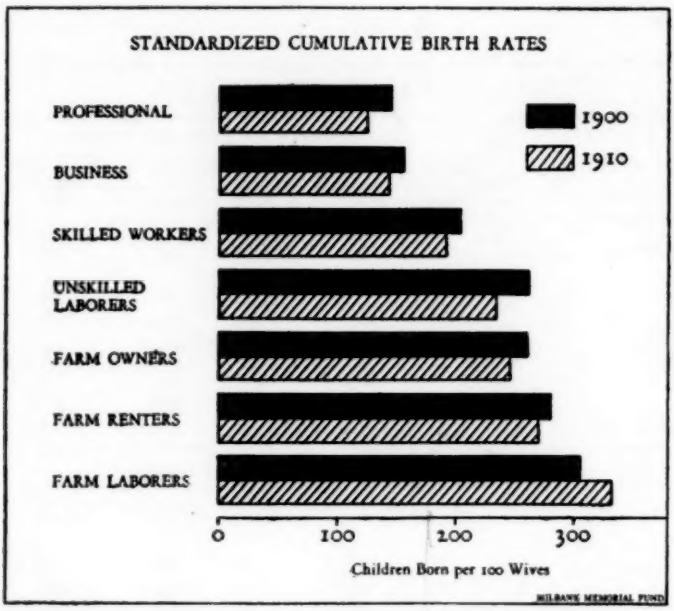

FIG. 4. STANDARDIZED CUMULATIVE BIRTH RATES FOR EACH SOCIAL CLASS IN 1900 AND 1910

The marked decline in the fertility of the total urban women and the slight decrease of the rates for the total rural women during the 1900-1910 decade have already been described. In Figure 2, the age-specific rates for each social class in 1900 and 1910 are presented. While the 1900-1910 differences do not appear to be large, the consistently lower rates of 1910 and the differences in the total rates standardized by age, tend to give significance to the declines as they are shown in graphs. The trends of the rates have not been uniform for specific social classes, however. The most significant changes in the urban classes during the 1900-1910 decade were the marked declines in

TABLE 8

Standardized Cumulative Birth Rates for Each Urban and Rural Social Class in 1900 and 1910

	1900	1910	PER CENT DECLINE
Urban Sample	193	173*	10.4
Professional	146	126	13.7
Business	157	144	8.3
Skilled workers	205	193	5.9
Unskilled laborers	263	236	10.3
Rural Sample	270	262	3.0
Farm owners	262	247	5.7
Farm renters	281	271	3.6
Farm laborers	306	333	+8.8

* *Cf.* Footnote 1, Table 3.

the fertility of the professional and unskilled laboring classes. The proportionate decreases in the total rates standardized for age for specific urban classes were as follows: professional, 13.7 per cent; business, 8.3 per cent; skilled workers, 5.9 per cent; unskilled laborers, 10.3 per cent. In the rural classes the decreases were: farm owners, 5.7 per cent; farm renters, 3.6 per cent; but the rate for the farm laborers showed an anomalous increase of 8.8 per cent.

The decrease in the fertility of the rural classes does not conform with reference to age to the pattern of the urban decline. The lack of more detailed statistics makes it impossible to account with any certainty for this difference. The absence of divergence with increasing age of the 1900-1910 rural rates may possibly be due to a greater frequency of passing from one social class to another. It is possible that farm laborers who advanced into the ranks of renters or owners during the decade tended to raise unduly the fertility rates of the owners and renters in 1910. Such a selective process might also account in part for the increase in rates of farm laborers if the individuals who remained in that class were excessively fertile. It is also conceivable that the rural-urban migration during the decade might have had the same effect upon the residue rural population. An adequate interpretation, however, would necessitate a further comprehension of the actual processes of cityward migration and of transference from one social class to another.

In considering the foregoing rates, it is necessary to keep in mind certain of their characteristics. In the first place, an unknown proportion of the wives included in the urban samples migrated to the city after all or part of their children were born. Doubtless there are others who migrated shortly before they were married. On the other hand, possibly a few of the women included in the rural samples really belong to the urban group. In a strict comparison of differences in fertility of rural and urban women, it would be desirable to eliminate rural wives from the urban samples and vice versa. No information was given on the original census schedules, however, which would make such corrections possible. The given rates represent differences which were found among samples of women actually residing in urban and rural districts at the time of the two enumerations, 1900 and 1910.

It is also necessary to remember that the rates given are simply for married women. They are not full measures of the extent to which various classes are reproducing themselves in that they do not take into account differences in the proportion of potential mothers who are married.

In general, the changes of fertility which took place were in the direction of lower rates and added differentiations according to social class. The fertility of the professional class became dissociated from the other white collar workers although even in 1910 the difference between the professional and business classes was less than that observed between other social classes. The urban unskilled laborers fell below the rural classes. There were also increasing differentiations within the rural group. At all ages and especially among women 25 years of age and over the age-specific rates for the farm laborers were higher than those for farm renters and farm owners. The age specific rates for the farm owners and farm renters were practically identical for women under 35 years of age, but among women 35 and over the rates of the farm owners were quite lower.

APPENDIX I

Previous Studies of Differential Fertility from the Division of Research, Milbank Memorial Fund

(a) SYDENSTRICKER, EDGAR, and NOTESTEIN, FRANK W.: Differential fertility according to social class. *Journal of the American Statistical Association*, March, 1930.

(b) NOTESTEIN, FRANK W.: Social classes and the birthrate. *Survey Graphic*, April, 1931.

(c) NOTESTEIN, FRANK W.: Differential age at marriage according to social class. *The American Journal of Sociology*, July, 1931, xxxvii, No. 1.

(d) BERRY, KATHARINE: Differential fertility according to geographic areas in the United States. *The Quarterly Bulletin of the Milbank Memorial Fund*, July, 1931, ix, No. 3.

(e) NOTESTEIN, FRANK W.: The decrease in size of families from 1890 to 1910. *The Quarterly Bulletin of the Milbank Memorial Fund*, October, 1931, ix, No. 4.

(f) SYDENSTRICKER, EDGAR: A study of the fertility of native white women in a rural area of Western New York. *The Quarterly Bulletin of the Milbank Memorial Fund*, January, 1932, x, No. 1.

(g) NOTESTEIN, FRANK W., and SALLUME, XARIFA: The fertility of specific occupational groups in an urban population. *The Quarterly Bulletin of the Milbank Memorial Fund*, April, 1932, x, No. 2.

(h) NOTESTEIN, FRANK W.: The relation of social status to the fertility of native-born married women in the United States. *Problems of Population*, edited by G. H. L. F. Pitt-Rivers, Honorary General Secretary, International Union for the Scientific Investigation of Population Problems, *London*, George Allen and Unwin, Ltd., 1932, pp. 147-169.

(i) SALLUME, XARIFA, and NOTESTEIN, FRANK W.: Trends in the size of families completed prior to 1910 in various social classes. *American Journal of Sociology*, November, 1932, xxxviii, No. 3.

(j) KISER, CLYDE V.: Fertility of social classes in various types of communities of the East North Central States in 1900. *Journal of the American Statistical Association*, December, 1932, xxvii, No. 180.

A STUDY OF DENTAL CARIES IN PORTO RICAN CHILDREN

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INTRODUCTION

As there is considerable evidence that dental caries may be influenced by diet, we measured the frequency and extent of caries in the teeth of Porto Rican children and studied the relation of caries to socio-economic factors which we suspect may be associated with variations in diet.

These measurements were made by three Porto Rican dentists examining with fine explorers and mirrors in a good light. The accuracy of their observations was tested upon ninety-two cases by correlating the findings of each dentist against the other two dentists. These correlations ranged from .89 to .93. The number of carious first molars and the extent of the tooth destruction, filled and unfilled, was recorded and given relative score values according to the technic described in a recent research on dental caries by the American Child Health Association.[1]

This research has indicated the validity of these score values as an index of past liability to caries. Only caries of first molars is used because the research mentioned gave evidence that this measure of caries of these four teeth is adequate for determining the total caries tendencies of these age groups. It will be noted that this type of analysis only requires an index of total caries tendencies rather than a complete measure of all caries in individual mouths. Comparisons with children in Continental United States are based upon the American Child Health Association data (published and unpublished). The Continental material may be shown to be representative of white American born urban public school children.

[1] Public Health Aspects of Dental Decay in Children. School Health Research Monograph Number III. Raymond Franzen, Ph.D., Director of Research, School Health Study, American Child Health Association. American Child Health Association, *New York City*. 1930. 136 pages.

The analysis of the records definitely indicates a greater tendency for the development of caries in the urban children than in the poorest rural class of children. There is an indication that the more privileged socio-economic classes are not more immune to dental caries than the poorer classes but there is rather some tendency for the poorer children to manifest a greater immunity to caries. The rural "agregado" children—a very underprivileged social class—have as little or even less dental caries than the average native-born white child of Continental United States in spite of a total lack of dental service given these children and the considerable dental service rendered the Continental children.

THE DATA

Dental Caries in Urban and Rural Children

There appears to be a greater prevalence of dental caries in the first molars of Porto Rican urban children than of rural "agregado" children. This comparison is made in Table 1 where the high scores mean much caries and the low scores little caries.

TABLE 1

Dental Caries in Urban and Rural Agregado Children—A Comparison of Average Unfilled Caries Scores in First Molars—10-Year-Olds

SEX	RACE	AVERAGE SCORES		STANDARD DIFFERENCE	NUMBER OF CASES	
		Urban	Rural		Urban	Rural
Boys	0*	11.48	8.24	4.9	189	113
Boys	1	9.14	7.07	2.4	92	61
Girls	0	11.31	7.99	5.0	182	89
Girls	1	10.28	7.04	4.0	117	55

* The racial classification is as follows: Race 0 represented the group judged to be entirely free from Negro characteristics. Race 1 represented the group judged with almost no doubt to be free from Negro influence on the basis of the way the features impressed the observer. With the slightest suspicion as to skin color, even though dark complexion might be explained as sun effect, the case was classified as Race 1. The slightest doubt as to features was distinguished as not white and scored with Race 1 or 2, according to the degree of suspicion. Race 2 included the cases with definite suspicion. Race 3 included the cases with at least one definitely negroid feature. Race 4 included cases definitely Negro, but suspected as not being full-blooded Negro. Race 5 was reserved for the cases that were judged to be full-blooded Negro.

As the Standard Differences are greater than three in all groups except the boys Race 1, it appears likely that in any similar sampling of Porto Rican children we would find more caries in the urban children than in the rural "agregado" children.

The consistency of the tendency for urban and rural differences is further shown in Table 2, where the average unfilled caries scores are compared by children of urban home owning and home renting families and the rural children both "agregado" and "not agregado." We find, then, all the rural groups have on the average less caries than any of the urban groups except one, also the "agregado" average is slightly less than the "not agregado" figure.

TABLE 2

Dental Caries in Urban and Rural Children by Racial and Socio-economic Groups
A Comparison of Average Scores in First Molars—10-Year-Olds

	URBAN				RURAL			
	Race 0		Race 1		Race 0		Race 1	
	Owners	Renters	Owners	Renters	Not Agregado	Agregado	Not Agregado	Agregado
Average (Unfilled) Caries Scores								
Boys	11.66	11.18	8.66	9.97	8.94	8.24	8.57	7.07
Girls	11.20	11.48	10.14	10.61	8.38	7.99	8.68	7.04
Average Caries Corrected (Fillings) Scores								
Boys	.89	1.04	1.19	.94	00	00	00	00
Girls	.53	1.27	.33	.61	.12	00	00	00
Average Enamel Destruction Scores (Combined Unfilled and Filled)								
Boys	12.55	12.22	9.85	10.91	8.94	8.24	8.57	7.07
Girls	11.73	12.75	10.47	11.22	8.50	7.99	8.68	7.04
No. of								
Boys	116	73	58	34	62	113	28	61
Girls	111	71	81	36	65	89	25	55

As practically no dentistry had been available for the rural children and the urban children showed sufficient fillings to affect the amount of caries to a definite degree, it appeared advisable to consider also cavities that had been filled as well as unfilled cavities. Such a comparison is made in Table 3. The average scores here represent the sum of the scores for fillings and for unfilled caries or the number and extent of the cavities and are a measure of the enamel destruction of the tooth by caries whether filled or not.

TABLE 3

Dental Caries in Urban and Rural Agregado Children—A Comparison of Enamel Destruction Scores in First Molars—10-Year-Olds

SEX	RACE	AVERAGE SCORES		STANDARD DIFFERENCE	NUMBER OF CASES	
		Urban	Rural		Urban	Rural
Boys	0	12.42	8.24	6.2	189	113
Boys	1	10.24	7.07	3.4	92	61
Girls	0	12.13	7.99	6.3	182	89
Girls	1	10.70	7.04	4.6	117	55

All these Standard Differences are greater than three and therefore we may conclude that in any similar sampling of Porto Rican children, we would find larger enamel destruction scores in urban than in rural children of the "agregado" class.

It should be recognized that this comparison of average Enamel Destruction Scores may involve an error because of the difference in the number of fillings of the urban and rural children. The cavity preparation incident to fillings would generally cause the measure of caries to be larger than the same cavity was before filling but this effect is offset in some degree at least by the conservation effect of the filling in stopping the further extension of caries in the tooth filled. Evidence of this well recognized conservation effect is presented in Chapter III of the Monograph "Public Health Aspects of Dental Decay in Children" already mentioned.

If the fillings had been made recently, then the conservation effect of the fillings would not be manifested and any extension of the cavity incidental to filling would tend to increase the enamel destruction scores.

Although no knowledge is available as to the time when the fillings were made, it seems reasonable to assume that all the urban children could not have had dentistry so recently that the conservation effect had not had time to influence the scores in a manner to hold back the extension of caries. The higher scores of the urban children when only unfilled caries is considered give a strong suggestion that a greater susceptibility to caries of the urban children has not been offset by a greater amount of dental service.

The tendency for a high caries prevalence among the urban children was further tested by separating all the Caguas and San Juan children and determining their average enamel destruction scores by both race and sex groups. Table 4 shows that the average scores from both these cities are consistently high and there is not enough difference from

TABLE 4

Dental Caries in Urban Children—Average Enamel Destruction Scores in First Molars—10-Year-Olds

	AVERAGE SCORES				NUMBER OF CASES			
	Boys		Girls		Boys		Girls	
	Race 0	Race 1	Race 0	Race 1	Race 0	Race 1	Race 0	Race 1
Public Schools								
San Juan	12.82	11.15	12.87	11.85	49	26	52	26
Caguas	13.00	12.53	9.57	9.07	28	17	14	15
Private Schools								
Ponce	13.31	....	10.17	....	13	..	18	..
Yauco	19.67	....	9.00	....	3	..	4	..
Mayaguez	14.00	....	12.86	16.00	3	..	14	1
San Juan	10.50	....	10.85	13.50	30	..	60	2

	Boys			Girls			Boys			Girls		
	Race 3	Race 4	Race 5	Race 3	Race 4	Race 5	Race 3	Race 4	Race 5	Race 3	Race 4	Race 5
Negroes—												
San Juan	13.56	10.71	11.10	10.06	10.48	10.71	18	77	20	17	77	17

the other urban figures to lead us to believe that the total average urban scores had been materially influenced by the condition of the children in these two cities. A high prevalence of caries in the San Juan children is also shown among the three Negro race groups distinguished as Races 3, 4 and 5. The average enamel destruction scores of the Negroes is shown in Table 4. In the private schools of four cities among 10-year-old children, chiefly from the urban population, we determined the average enamel destruction scores, (Table 4). We found a similarly consistent tendency for a high caries prevalence.

Although the averages for these groups are based on an inadequate sampling for conclusions as to the caries tendencies of the individual groups, the figures are generally valuable because of the consistent support they give to our interpretation that some factor associated with urban conditions is concerned with a high dental caries prevalence.

Socio-economic Status and Dental Caries

Rural Children—As already noted Table 2 shows the average caries among rural children is slightly less for the "agregado" children than for the "not agregado" groups. This finding plus the high prevalence of caries found among the private school children suggested that there may be a greater susceptibility to caries among children of the better socio-economic groups. The urban children also show a slight difference in averages between the Race 0 and Race 1 groups with more caries in the former. As there was also a slight difference in the anthropometric traits of the two race groups distinguished as Races 0 and 1, which was suspected as being concerned with a socio-economic distinction, we are inclined to consider this difference in average caries scores as of possible significance. If the effort to distinguish Races 0 and 1 involved a socio-economic distinction in favor of Race 0 children, then more caries among the Race 0 group would be consistent with the high caries prevalence among the private school children and the suspected difference between the "agregado" and "not agregado" groups.

The correlations of caries scores of rural "agregado" children with several socio-economic variables were zero or showed no definite tendency. This finding corresponds with the lack of relation between the anthropometric traits and socio-economic variables which we suspect may be due to very little variation in important socio-economic distinctions in this poor, underprivileged group. If susceptibility to caries is to some extent influenced by genetic factors, it is reasonable to expect

that other influences that may be associated with socio-economic variables might be swamped by genetic factors when the socio-economic variation is small, or inaccurately distinguished, or not associated with important dietetic or other possible correlates.

The rural "not agregado" group on the other hand shows correlations suggesting a definite tendency for children in the better economic classes as indicated by these socio-economic variables to have more caries than in the poorer economic classes. These correlations are shown in Table 5.

TABLE 5

Relation of Certain Socio-economic Factors to Dental Caries in First Molars
Rural Children "Not Agregado"

CORRELATION OF 1ST MOLAR CARIES SCORES WITH:	10-YEAR-OLDS				8-YEAR-OLDS			
	Boys		Girls		Boys		Girls	
	Race 0	Race 1	Race 0	Race 1	Race 0	Race 1	Race 0	Race 1
Economic Rating..	—.10	—.10	—.15	.12	—.11	—.21	—.40	—.52
Persons per Room	—.05	—.28	—.02	—.01	—.26	—.35	—.18	—.15
Rooms in House..	.07	.15	—.04	.05	.23	.30	.27	.33
Number of Cases	62	28	65	25	61	40	59	30

Although these correlations are low, they are all so consistent with other data pointing to an interpretation that the higher socio-economic groups have the most caries that we are led to consider the relationship as probably significant. This interpretation is explained in the following paragraphs.

The rating scale of rural socio-economic status [2] gives the highest scores to the children of the lower socio-economic groupings. Scores ranged from 4 to 8 according to the 13 class divisions. The negative correlations, therefore, indicate that the poorer economic groupings have the lower caries scores or less caries and the better economic classes have a tendency to be associated with the worst caries. It appears

[2] A study of factors associated with the growth and nutrition of Porto Rican children. Harold H. Mitchell, M. D., Research Division, American Child Health Association. *Human Biology*. Vol. 4, No. 4, 1932, p. 503.

significant then that all these correlations are negative except with the 10-year-old girls Race 1.

The number of persons per room reported by each child for his home gives us another criterion for differentiating the children on the basis of the relative crowding in their homes. Children from homes with few persons per room therefore would generally be of a higher socio-economic status and vice versa. It appears significant then that none of the correlations are positive and five out of the eight correlations are between —.15 and —.35. Such relationships appear to indicate that the children from homes with less crowding or better economic groupings have a tendency to have more caries than children from the more crowded homes.

The children from homes with a larger number of rooms in the house would generally be of the better socio-economic classes. The five positive correlations with the other correlations practically zero appear to indicate that children from the homes with a large number of rooms or better socio-economic class have a tendency to have more dental caries than children from the poorer socio-economic groupings with fewer rooms per house.

The correlations of grade in school with dental caries are so low that their significance is questionable and therefore they were not included in the table. The three of these correlations, however, which are not as near zero as the others are positive which would be consistent with the other relations presented; i. e., the children farther advanced in school have more caries.

Urban Children—The same tendency for more dental caries to be associated with the better economic classes was investigated further with urban children. As there were a number of urban children who had had dental service (fillings) it was necessary to make allowance for this influence upon the dental caries scores. It was found that the relationships of socio-economic status and dental caries were consistent with the other findings when allowance was made for the dental service by using the enamel destruction scores (combined corrected (filled) and uncorrected (unfilled) dental caries scores) instead of merely uncorrected dental caries scores. These results are shown in Table 6.

It may be seen that there appears to be a slight tendency for children from homes with the higher tax valuation to have more dental caries than is found for children from homes with the lower tax valuation.

TABLE 6

Relation of Certain Socio-economic Factors to Enamel Destruction Scores 10-Year-Old Urban Children

CORRELATION OF ENAMEL DESTRUCTION SCORES WITH:	BOYS				GIRLS			
	Race 0		Race 1		Race 0		Race 1	
	Owners	Renters	Owners	Renters	Owners	Renters	Owners	Renters
Property Valuation	.05	..	.12	..	.18	..	.15	..
Monthly H. Rent	..	.24	..	—.01	..	.05	..	.00
Persons per Room	—.09	.01	—.28	.04	.00	—.01	—.09	—.14
Rooms in House..	.14	.21	.34	.03	.27	—.14	.19	.16
Number of Cases	116	73	58	34	111	71	81	36

The correlations with number of persons per room should be negative in order to be consistent with the tendency for the better economic group to have the most caries. We find these correlations also generally zero or very low but there are two negative correlations of —.14 and —.28 which are suggestive of more caries among children from homes where there is the least crowding, or the better socio-economic groupings.

The number of rooms in the house appears to show this tendency, slightly more marked as the correlations are higher with only one zero correlation (.03) and one —.14.

Although these correlations are low the preponderance of the tendency is consistent with the other indications suggesting that children from the homes of better socio-economic status have more total caries (corrected and uncorrected) than children from the poorer homes.

It must be recognized that these correlations involve the same possible errors that may result from the use of enamel destruction scores as was explained under the discussion of urban and rural differences. Such possible error is not involved with the correlations computed for rural children because the fillings are negligible. We also found a definite relationship between the socio-economic variables and the proportion of caries corrected. Table 7 shows that this relationship indicates as might be expected that the more privileged socio-economic groups have the highest proportion of carious cavities filled.

TABLE 7

Relation of Certain Socio-economic Factors to Proportion of Total Caries Corrected (Carious Cavities Filled)—10-Year-Old Urban Children

CORRELATION OF ENAMEL DESTRUCTION SCORES WITH:	BOYS				GIRLS			
	Race 0		Race 1		Race 0		Race 1	
	Owners	Renters	Owners	Renters	Owners	Renters	Owners	Renters
Property Valuation	.22	..	.53	..	.08	..	.10	..
Monthly H. Rent	..	.14	..	.66	..	.30	..	.59
Persons per Room	—.28	—.13	—.25	—.31	—.19	—.14	—.20	—.14
Number of Cases	116	73	58	34	111	71	81	36

This relationship is probably not higher because of the tendency for little dental service among all classes including the well-to-do and because of the effect of free clinic services for the poor in some cities. Since the higher socio-economic status has the larger proportion of the carious cavities filled, we should expect this dental service might reduce the total amount of enamel destruction by holding back the extension of caries. Table 6, however, shows more the opposite tendency with the higher socio-economic status manifesting more enamel destruction, and when unfilled caries scores were correlated with two of the socio-economic variables we found no definite tendency.

The tendency then seems to be in favor of a greater caries susceptibility among the children of more privileged socio-economic status and more immunity to caries among the poorer children. This inquiry we believe should be pursued further by using other socio-economic variables and relating them to an appropriate index of non-carious teeth in order to avoid the effect of dentistry.

We may conclude that the evidence of a tendency for the more well-to-do children to have more caries than poor children is sufficiently strong to warrant us to advise further study of so extraordinary a condition. School Health Research Monograph Number IV concerned with socio-economic correlates of health factors indicates from the interrelation of eight socio-economic variables that children of the Conti-

nental United States show the opposite tendency.[3] Continental children of the more privileged socio-economic status have more immunity to dental caries than poorer children. That this tendency is well marked is shown by the multiple correlation of .53 between the eight socio-economic measures and the average number of non-carious first molars per mouth and a multiple correlation of .52 between the eight factors and the enamel destruction scores computed in the same manner as in our Porto Rico study. If further investigation shows this contrast with Continental conditions is really as clearly defined as we are led to believe from this study, it seems likely that research to determine the cause of this phenomenon might reveal valuable information contributory to the control of dental caries.

DENTAL CARIES IN PORTO RICAN AND CONTINENTAL UNITED STATES CHILDREN

As it is probable that quite different dietary conditions for children prevail in the United States, it is of interest to compare the teeth of Porto Rican children with those of children in Continental United States. Of course, dentistry on the Continent contributes considerably to conserving teeth from enamel destruction due to caries and, therefore, to the elimination of high scores for uncorrected caries. The average uncorrected dental caries scores for 10-year-old Continental children is as might be expected considerably less than the best scores in Porto Rico where little or no dental service is given; e. g., the average score for United States continental children is 4.5 which may be compared with the average unfilled caries scores for Porto Rico of from 7.04 to 11.66 (as may be noted in Table 2). However, if we combine the uncorrected with the corrected dental caries score for continental children, we have a better index of total enamel destruction resulting from caries in continental children and we may then determine whether the continental children have much less enamel destruction than the Porto Rican "agregado" children who have no dental service. The comparable scores are as follows:

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[3] Influence of Social and Economic Factors on the Health of the School Child. School Health Research Monograph Number IV. Raymond Franzen, Ph.D., Director of Research, School Health Study, American Child Health Association; American Child Health Association, *New York City*, 1932, 144 pages.

TABLE 8

Comparison of Total Enamel Destruction in Children of Continental United States and Porto Rico—10-Year-Olds

GROUP	ENAMEL DESTRUCTION SCORE
Continental United States	
Both Sex Groups	8.11
Porto Rico—Rural "Agregados"	
Boys—Race 0	8.24
Race 1	7.07
Girls—Race 0	7.99
Race 1	7.04

This comparison indicates that the rural "agregado" children in Porto Rico must have no greater tendency for loss of enamel structure than the average found in Continental United States in spite of the dental service received by continental children. Of course the combined scores for Continental children are increased somewhat by the extension of the surface area for the fillings but when we consider that none of these groups of rural "agregado" Porto Rican children showed evidence of a single filling and when we consider the similarity of these scores, we are impressed that there must be some tendency for the Porto Rican rural "agregado" children to have a certain tendency to immunity against dental caries that is not present in the urban Porto Rican children nor in some of the groups in Continental United States where caries is more prevalent than the average. On the other hand we find that the average enamel destruction scores for urban Porto Rican children shown in Tables 2, 3, and 4 are higher than the average found for Continental children.

If we compare the average number of non-carious first molars per mouth of United States continental urban children with the various groups of Porto Rican children, we have an index of the resistance against caries for comparison that has not been affected by the greater amount of dental service available in the Continental United States. This comparison is shown in Table 9.

The comparison indicates a definite tendency for rural "agregado" children to have more non-carious teeth and suggests a greater immunity to caries on the part of the rural "agregado" children from Porto Rico.

TABLE 9

Comparison of the Average Number of First Molars That are Non-Carious in Children of Continental United States and Porto Rico—10-Year-Olds

GROUP	AVERAGE NUMBER
Continental United States	.66
Porto Rico	
Urban—Race 0	.50
Race 1	.66
Rural—Both Race Groups	
"Not Agregado"	.74
"Agregado"	.90

A SUMMARY OF THE FINDINGS

1. There is a greater prevalence of dental caries in the first molars of Porto Rican urban children than is found in the rural "agregado" children. There is apparently a tendency in all urban Porto Rican children to have more dental caries than is common in rural children.

2. Private school children show the same tendency to caries that the urban public school children show, and they have more caries than the rural "agregado" children.

3. The study indicates a tendency for more caries in the better socio-economic groups than in the poorer groups.

4. The generally poor rural "agregado" children of Porto Rico appear to have no more enamel destruction from dental caries than the average for Continental children. Urban Porto Rican children tend to have more caries than Continental children. The comparison of the average number of non-carious first molars per mouth of Porto Rican children with Continental children indicates a possible greater immunity to caries in rural "agregado" children than in Continental children.

THE CONTRIBUTIONS OF THIS STUDY POINT TO FURTHER RESEARCH

Although the growth and development of Porto Rican children is apparently related to socio-economic conditions so that the private school children and those of the better socio-economic classes are larger in their skeletal frame and have larger musculature and greater amounts of subcutaneous tissue than the children of the less privileged socio-

economic classes, the better socio-economic status is associated with a greater tendency to dental caries and the poorest socio-economic group shows the least caries. This tendency of dental caries in Porto Rican children appears to operate in a reverse manner from that found among Continental United States children where there appears to be a greater immunity to dental caries among the more privileged socio-economic stratum than among the poorer children. All these findings appear to indicate that some influence is operative among the rural "agregado" children favoring a greater immunity to dental caries than exists among urban children and the children who appear to be favored with relatively larger growth and physical development. These findings are so striking and different from the expected association of sound teeth with good nutrition that the problem deserves further careful study and research.

Various hypotheses have been considered as to the explanation of this phenomenon. Urban families may be more dependent upon the rice and bean diet so much preferred by all classes. Fruits and tropical vegetable products may be more commonly used among the poorer rural classes than is generally appreciated. The poverty of the rural "agregado" group may reasonably be expected to limit the rice, beans and lard that are consumed by those obtaining more cash wages. It seems unlikely that more exposure of rural children to sunshine is the explanation. Further information on the mineral and vitamin properties of tropical products may not only explain our findings but yield a valuable contribution to the problem of controlling dental caries.

NOTE: The author wishes to acknowledge his indebtedness to the Director, George T. Palmer, Dr. P. H., and to the Staff of the Research Division of the American Child Health Association. In planning and analysis, Raymond Franzen, Ph.D., gave invaluable aid and advice, while the supervision of the statistical work was undertaken by Mayhew Derryberry who also contributed important advice and criticisms.

NOTES ON A FAMILY OF BREEDING GIBBONS

BY HAROLD J. COOLIDGE, JR.

A family of gibbons, *Hylobates concolor leucogenys,* was procured in Thakek, French Indo-China, by the Kelley-Roosevelts expedition of the Field Museum on July 6, 1929, and presented to the National Zoological Park at Washington by Colonel Theodore Roosevelt and Harold J. Coolidge, Jr.

The male was completely black except for prominent white side whiskers. He had an extremely friendly disposition, often putting his arms around the necks of the children in the village of Thakek.

The female had light tan-colored fur with a rounded black patch above the forehead produced backwards in the median line. When the family was discovered her disposition was unusually disagreeable and she very soon bit through the hand of the boy who was feeding her. She was nursing a young male about four months old with markings essentially like those of the father.

This gibbon family belonged for several years to the local administrator in Thakek, who had bred them in semi-captivity. They came into the writer's possession after the death of their owner.

During the two months' journey to Washington the baby was in a small cage along with its mother, and seldom ate solid food. He could only be fed with bananas or nuts when three pieces were put in the cage at once. The mother would immediately seize one piece in each hand, making it possible for the youngster to take the third piece.

Every morning, about eight o'clock, while crossing the Pacific on the boat, the female would cry out loudly making her characteristic call—ho-a! ho-a! ho-a!, her voice rising in pitch and the succeeding cries increasing in rapidity on each repetition. The male in the next cage would answer her with a booming cry of two notes very much less ear-piercing, but with a peculiar carrying quality. According to Gerrit S. Miller, Jr., the second note of this cry was always slightly lower in pitch than the first. Also, the male had another call, suggesting the final notes of the mourning dove's song, uttered with swelled throat and apparently with closed mouth. Neither animal ever used the other's cry. Mr.

Miller says further that the only sound that the two animals appeared to use in common was a high-pitched, birdlike chirping uttered during copulation, and he heard this only once. It was apparently produced by both. At breakfast, during the trip across the Pacific, all the passengers on the boat would talk of a baby in the steerage whose crying could be heard every morning even in the far corners of the ship.

On arrival in America, the gibbon family crossed the continent in an American Express car and the company thoughtfully telegraphed for fresh boiled rice to await them at each important station. The only damage they seem to have suffered from the five-day train journey was that the baby bit a piece out of its mother's ear when passing through Chicago.

FIG. 1. FEMALE GIBBON AND YOUNG AT REST, RIGHT SIDE VIEW
Note the clinging position of the baby.

When the family arrived at its destination, the National Zoological Park, on August 21, 1929, the young one was separated from his mother, and he lived an uneventful life until his death on January 31, 1931. Also on arrival, the adults were again placed together and remained in good health for more than a year.

MANNER OF COPULATION OF GIBBONS

Copulation was frequent. It has been thus described by Gerrit S. Miller, Jr., in manuscript notes that he has placed at my disposal.

FIG. 2. FEMALE GIBBON AND YOUNG AT REST, REAR VIEW
Note the relative use of arms and legs in clinging to the mother.

January 9, 1930. Copulation of *Hylobates leucogenys* seen twice (December, 1929; January 9, 1930). Both times the animals were hanging by their hands from the top bars of the cage. The female placed her feet on a lower support so as to raise her knees and cause her pelvis to sag and project backward. (A posture indicated in Smithsonian Scientific Series, Vol. 9, pl. 70, December 17, 1931). The male then swung himself up behind and curved his pelvis under hers. As soon as the male was in position the female let go with her left hand (*left* both times) and threw the left arm around the male's neck and shoulders, thus pressing her body against his and aiding in every possible way the close adjustment made necessary by the male's short penis. The pelvic strokes of the male were many (not counted, but seemingly much more numerous than in *Macacus rhesus*) but short and not very animated, with no obvious climax. The male's penis retained its erection for about a minute after the animals separated (first time—not observed second time, but his position was not favorable). During the act both animals were silent, though the first time they had just finished one of their noisy duets. In neither instance did the male grasp the female in any way either with hand or foot.

February 9, 1930. From 11.45 to 12.00 the gibbons were constantly engaged in sexual play, after a considerable period of rest. Complete copulation appeared to take place twice. Process exactly the same as previously observed, the female each time aiding adjustment by throwing her left arm behind the male's neck and shoulder; but there was never any grasping of either animal by the other. At the height of the excitement there was much chirping apparently by both, a sound not heard before, not very loud, and entirely different from the ordinary cries. During the play between the two copulations the male would invite the female by swinging past her and lightly tapping her with one hand. She would respond by following him, whereupon he would swing behind her and attempt to make adjustment. Once they experimented with the female standing half erect on the shelf at the back of the cage. The male clung to the bars with both hands and let his feet rest on the shelf. The adjustment was very poor and the attempt was soon abandoned.

THE BEHAVIOR OF A BABY GIBBON

On December 27, 1930, the mother gave birth to a baby. Again it was a male. Its first coat was whitish except for a fringe of black eyebrows. This event is the first recorded birth of a gibbon in Europe or America. The only other records, according to Yerkes and Yerkes, are the births of two gibbons reported by Ogilvie in March 1920 in Prae, Siam, and that of two reported by Robinson in the Rangoon Zoological Gardens in 1923 and 1924. Unfortunately, in the case that we are recording, no observations of parturition were made, but the following notes on mother and young were supplied by Mr. Blackburne, head keeper of the National Zoological Park:

The baby gibbon was born on December 27, 1930. It was white in color, and a male. It did not cling to the mother's breast as young monkeys usually do but

lay crosswise in her thighs. The mother, when she climbed about the cage, would draw up her hind legs and form a pocket and the young one lay crosswise with its fore legs on one side of the body and its hind legs on the other. When the mother would sit down the baby would take an upright position and nurse. The mother and baby seemed to be thriving nicely and the baby was growing rapidly. After two weeks it would venture a short distance from its mother on its own. At three weeks of age the young was noticed to be failing and both mother and baby had diarrhea. The baby died January 25, 1931.

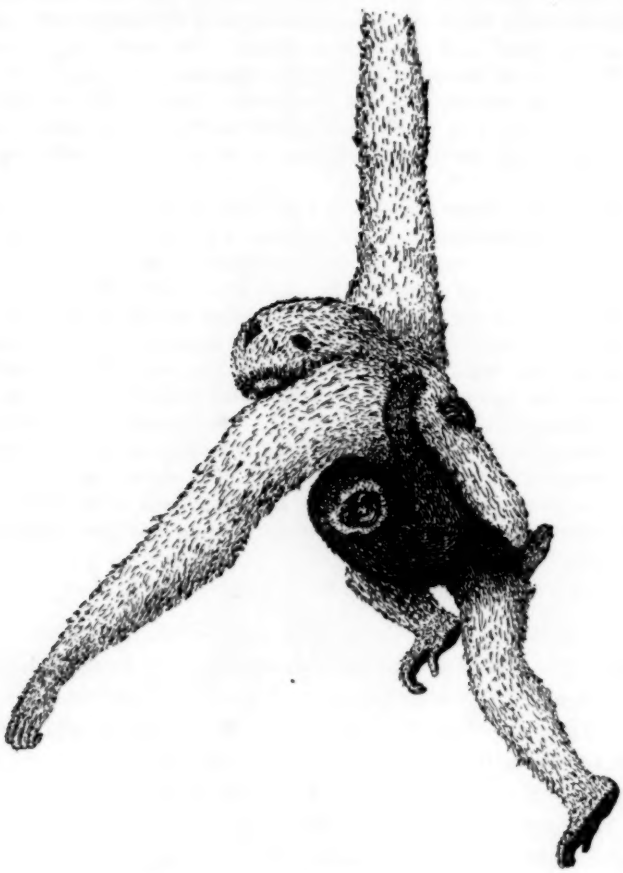

FIG. 3. FEMALE GIBBON AND YOUNG WHEN FEMALE IS BRACHIATING OR REACHING FOR FOOD, LEFT SIDE VIEW

Note the position of the baby does not interfere with her locomotion.

After her sickness in January, the female recovered and remained in good condition until June, when she began to suffer again from diarrhea. This time the result was fatal. Both the adults died during July, 1931, the female on the 11th and the male on the 27th. After the death of the female the male, though apparently in good physical condition, refused food and wasted away until he died, showing great distress at the loss of his mate. The company of a spider monkey that was put in the cage with him did not help at all.

FIG. 4. FEMALE GIBBON AND YOUNG AT REST
The mother is annoyed with her baby and having grabbed it by the back of the neck has pulled it away from her body. The young animal is frightened by this treatment but is entirely helpless.

One of the most notable things about these gibbons was their extraordinary precision and coördination of movement in timing the speed of moving objects in the air. I often noticed while watching the gibbon family that when a piece of fruit or food was thrown to one or the other from a distance, instead of reaching out and grabbing it quickly, the animal would reach out slowly and pick the object out of the air, never once failing to catch it. When recorded in a moving picture this unusually well-timed action gave all the appearance of slow motion.

The same type of unhurried action appears in their ability to hurl themselves accurately through the air to "distances of thirty or even forty feet without evident difficulty or hesitation" (Yerkes). Martin describes a gibbon catching a live bird with one hand in mid-air while in passage between two branches.

The four drawings in this paper were made by Mr. Arthur Johansen, staff artist in the Department of Biology of the School of Hygiene and Public Health of the Johns Hopkins University, from moving-picture photographs made in Indo-China by the author.

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